CSIR COLLEGE OF SCIENCE AND TECHNOLOGY

GROWTH OF COCOA SEEDLINGS WITH SOIL AND FOLIAR AMENDMENTS AT THE NURSERY IN AKIM TAFO IN THE EASTERN REGION OF GHANA

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2021

CSIR COLLEGE OF SCIENCE AND TECHNOLOGY (CCST)

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BY

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Thesis submitted to the Department of Soil Resources Management of the CSIR College of Science and Technology, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Soil Health and Environmental Resources Management

JANUARY 2021

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this College or elsewhere.

Candidate's Signature:…………………………….Date:……………………

Anna Dzigbordi Mensah

Supervisors' Declaration

I hereby declare that the preparation and presentation of the dissertation were supervised in accordance with the guidelines on supervision of thesis laid down by the CSIR College of Science and Technology.

Supervisor's Signature:…………………………….Date:……………………

Name: Dr Francis Tetteh

Co- Supervisor's Signature:………………………..Date:……………………

Name: Dr Emmanuel Amoakwah

ABSTRACT

This study was to search for an alternative means of raising healthy cocoa seedlings at the nursery that will accelerate seedling growth. The objective of the study was evaluating the growth of cocoa seedlings treated to soil and foliar amendments at the nursery at Akim Tafo in the Eastern region of Ghana. The experiment was laid out in a Completely Randomized Design with three replicates and nine treatments. The following nine treatments were imposed on the soil in the polythene bags: T1-Inorganic liquid Fertilizer-Sildaco10:10:10: 0.42 ml. T2- Fertilizer-Sildaco10:10:10: 0.84ml. T3-NPS14-31-0-S Inorganic Granular Fertilizer 0.6g. T4-NPS14-31-0-S Fertilizer 1.2g, T5-Green OK Organic liquid fertilizer 0.42 ml. T6-Green OK 0.84 ml. T7-Elite (Organic granular) 4.5g. T8-Elite 9.0g and T9-Control. The experiment was conducted from January 2020 to July 2020. Hybrid cocoa seedlings were transplanted and allowed to grow for seven months. The fertilizers increased significantly (P>0.05) the plant height, stem diameter, number of leaves, fresh root and shoot weights and dry root and shoot weights of cocoa seedlings especially organic solid fertilizer. The treatments also increased significantly (P>0.05) soil and leaf N, P, K, Ca, Mg, Na, soil pH relative to the control. Treatment 3 &4 NPS was high in pH content of the soil. Elite organic fertilizer double dose was recommended for cocoa seedlings at the nursery for Cocobod. In conclusion using of fertilizer will help increase growth of cocoa seedling and give a healthy strong cocoa to boost the nation economic stability especially organic fertilizers that will not affect the environment. Elite organic fertilizer double dose was recommended for cocoa seedlings at the nursery.

DEDICATION

To wonderful daughter, Clare Ama Osei Mensah, mother, Mrs. Vincentia Mensah and the entire Mensah family.

ACKNOWLEDGEMENT

I am deeply indebted to my supervisors, Dr Francis Tetteh and Dr Emmanuel Amoakwah for their guidance, patience and immense support throughout this study. From the first day of contact, Drs. Tetteh and Amoakwah were a constant source of inspiration, drive and enthusiasm. I appreciate very much their constructive criticisms of my ideas. May the good Lord bless them and their families.

I also acknowledge the support of Mr. Alex Afrifa, Mr. Jerome Agbesi, Dr Alfred Arthur, Mr. Samuel Yeboah, Mr. Dickson Agyapong, Mr. Divine Addo, Mr. Edmund Omane, Sister Mary Pokuawaa, Linda Larbi, Mr. Quarshie, Samuel Awudjah, Emmanuel Cudjoe, Gladys Okletey, Alberta Badu Yeboah, Mr. Kofi Nuamah Appiah and Mr. Otuo all of CRIG.

To the national service personal for their help during soil sampling. Mr. Joshua, Seth and Robert and all the staff of the Soil Science Division for their support and encouragement. May the almighty God richly bless you and his favour never departs from you. Academic support from my mates, especially, Prince Addai and Samuel Benefo and senior Mr. Eric Asamoah and Mr. Gideon Asamoah of CSIR-SRI.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
Ca	Calcium
Cm	Centimetre
Dm	Decimetre
C	Degree Celsius
g	Gram
PH	Hydrogen ion potential
kg	Kilogram
L.S.D	Least Significance Difference
Mg	Magnesium
mm	Millimetres
u	Micro
mg	Miligram
meq	Miliequivalent
N	Nitrogen
OC	Organic Carbon
%	Percentage
P	Phosphorus
K	Potassium
SOM	Soil Organic Matter
VPD	Vapour Pressure Deficit

CHAPTER ONE

INTRODUCTION

Background to the Study

This study was to evaluate the growth of cocoa seedlings using soil and foliar amendments at the nursery. A search for an alternative means of raising healthy seedlings at the nursery that will accelerate seedling growth was what this trial investigated. Most surface soils fail to provide adequate and balanced amount of nutrients for essential and optimum growth and development of seedlings at the nursery (FAO, 1999). Cocoa cultivation is a major source of livelihood for over a million farmers and their dependents in rural communities of Ghana and contributes actively to the economy of these communities (Baah, 2008). Attempts by farmers to increase cacao production are currently achieved through the establishment of new farms and the rehabilitation of aged/unproductive farms with mixed hybrid seedlings.

Cocoa is a tree crop that provides livelihoods for millions of smallholder farmers in over fifty (50) countries across Africa, Latin America, the Caribbean and Asia (Peprah, Amoah, & Akongbangre, 2019). It grows best in humid, tropical zones located roughly 10 degrees north and south of the equator (COCOBOD, 2001). The cocoa tree (Theobroma cacao) grows only under very humid conditions. It needs a climate of humid, warm and preferably constant temperatures between 25°C and never above 35°C. Sufficient rainfall is essential and soil requirements must be humid and rich in nutrients. Cocoa pod colour depends on variety, ranging from yellow, red to reddish-brown when matured (Wood & Lass, 2001).

Cocoa (*Theobroma cacao* L.), belongs to the family Sterculiaceae (Wood and Lass, 1985). Recently, with molecular marker technique cocoa has been classified to belong to the family Malvaceae (Alvenson, Whitlock, Feller, Bayer, & Baum, 1999; Fagbohum, Anibijuwon, Oluwole, 2011). Theobroma's genus has twenty-two (22) species. However, the only species grown commercially produce seeds for chocolate making or for the extraction of cocoa butter is Theobroma cocoa (Mossu, 1992a).

Cocoa (Theobroma cacao) is a small, wide-branching evergreen tree that is native to tropical rainforest areas. Cocoa cultivation requires a well-drained, well aerated soil with good crumb structure which contains adequate supplies of water and nutrients. Cocoa seedlings requires nutrients such as nitrogen, phosphorous, potassium, etc. and metabolites (proteins, lipids, carbohydrates) for their growth and development (Gockowski, Weise, Sonwa, Tchata, & Ngobo, 2004). The establishment of cocoa farms has been popular with the use of nursed seedlings in polybags. Availability of fertile topsoil for nursing cocoa seedlings is becoming limited and poor seedling growth of cocoa in the nurseries has been ascribed to the use of unsuitable potting media (Gockowski *et al*.).

The polybags also allow the nursery period to be prolonged until the environment is conducive for transplanting to the field. These polybags are filled with topsoil. The major problem associated with the use of topsoil as seedling medium is the scarcity of topsoil (Hebel, 1994). This problem is compounded by inadequate quantities of fertile topsoil for potting cocoa (Hebel). With the introduction of the cocoa rehabilitation programme in Ghana, different types of soils are used for filling the polybags.

These soils differ in their fertility status, with the less fertile soils impacting negatively on the growth of cocoa seedlings. There is therefore, the need to search for suitable materials / soil additives with the view to improve the fertility status of the soils used for raising healthy cocoa seedlings. Raising of cocoa seedlings in nurseries using polybags is the recommended practice because the management of individual seedlings results in much vigorous and improved capability of successful establishment. A potting medium is a composition of organic materials formulated to achieve desirable chemical and physical needs required by the crop to attain its potential growth and development.

Cocoa is one of the most important tropical cash crops with West Africa contributing about 70 percent of the world's cocoa (FAOSTAT, 2012). Cocoa is a major raw material used in the production of cocoa powder, chocolate based product, biscuits and confectioneries. Processed cocoa beans are used to make sweets, sweetening products, cocoa butter and perfume as well as used in pharmaceuticals. Bearden, Keen & Steinberg, (2003) found that cocoa contains important nutrient elements and several minerals including calcium, copper, magnesium, phosphorus, potassium, sodium and zinc. Its seeds are used to make cocoa powder and chocolate (Mehta, 2013).

Cocoa is the lifeblood of Ghana's economy and the heartbeat of Ghana's socio-economic development. The crop in 2012 contributed 18% to Ghana's Gross Domestic Product (GDP) (Ghana Statistical Service, 2015). Views are sometimes even expressed that the inability of weather conditions in the three Northern regions of the country to support cocoa production is one of the reasons why they are the poorest regions of Ghana, and that if cocoa production was possible there; their economies would have been transformed by now.

Health benefits of cocoa include decreased inflammation, improved heart and brain health; blood sugar and weight control and healthy teeth and skin (Katz, Doughty, & Ali, 2011). The appropriate and recommended use of organic and inorganic fertilizers will improve the fertility of nutrient deficient soils which would in turn improve the growth performance of cocoa seedlings (Fidelis & Rajashekhar, 2017).

Statement of the Problem

Poor growth of cocoa seedlings in the nursery has been related to the use of unsuitable potting media and the problem of adequate quantities of fertile topsoil for raising cocoa seedlings. Top soils normally used in raising cocoa seedlings for transplanting in farms cannot effectively support vigorous seedling growth due to its low nutrient composition and non-degradable materials (Arthur, Dogbatse, Quaye, & Konlan, 2019). There is therefore a problem of procuring fertile soils or formulating adequate quantities of fertile topsoil for raising cocoa seedlings for farm establishment to address the need for a good soil management package for the nursery to ensure vigorous growth (Ofori-Frimpong, Afrifa, & Acquaye, 2006), to address the need for a good soil management package for the nursery to ensure vigorous growth.

Purpose of the Study

This work is to address the issue of suitable fertilizer formulations for nursing cocoa at the nursery.

Research Objectives

Therefore the main objective of this study is to assess the performance of cocoa seedlings with selected organic and inorganic fertilizer applications.

The specific objectives were set to:

i. Evaluate different fertilizer formulations used for raising cocoa seedling at the nurseries.

ii. Examine the influence of foliar and granular fertilizers on the growth performance of cocoa seedlings.

Research Questions

i. How will different fertilizer formulations help to raise healthy cocoa seedlings at the nursery?

ii. How foliar and granular fertilizers will help improved the growth and performance of cocoa seedlings?

iii. How will organic and inorganic fertilizers improve the growth of cocoa seedlings at the nursery?

Hypothesis

1. Application of soil amendments will not improve growth of cocoa seedlings.
2. Application of foliar amendments will not improve growth of cocoa seedlings.

Significance of the Study

Considering the significant contribution of cocoa to the country's economy, more cocoa seedlings need to be raised to augment the long term sustainability of cocoa production in Ghana. The need to alternatively look for ways of raising more vigorous cocoa seedlings for farm establishment has paved way for the use of organic and inorganic fertilizers to readily make available to the plant soil nutrients necessary for better cocoa seedling growth. For sustainable cocoa seedling production including the recovery of soil fertility in degraded areas, both organic and inorganic fertilizer formulations are recommended (Afrifa, Ofori-Frimpong, Acquaye, Snoeck, & Abekoe, 2010). The use of organic and inorganic fertilizers in potting media would not only improve the growth performance of cocoa seedlings but would also improve the quality of soil used in raising seedlings (Adejobi, Akanbi, Ugioro, Adeosun, & Mohammed, 2013). This would ensure adequate plant nutrients for the seedlings to boost its survival and establishment rates during field transplanting (Arthur et al., 2019).

Delimitation

There are several fertilizer formulations for cocoa seedlings but the study limited itself to soil and foliar amendments.

Limitations

There were limitations in the evaluation on the different soil amendments used for the raising of cocoa in the nursery at the Cocoa Research Institute of Ghana main nursery. Some of the limitations encountered are:

i. Insects such as defoliators feeding on the leaves.
ii. The machine for determining plant leaf area was scarce.
iii. The fume chamber was not working and this delayed the analysis of the samples.
iv. Shortage of concentrated sulphuric acid at the laboratory delayed data on plant sample analysis.

Organisation of the Study

In addition to references and other relevant appendices, the study is organized into five (5) main chapters. Chapter one gives details of the background of the study, the problem statement, objective, research questions and the significance of the study. Chapter two shows literature reviews of both theoretical and empirical literature. Chapter three illustrated how the research was carried out and the methodology employed. Chapter four involve the results, analysis and discussions of the data. Chapter five entails summary of findings, conclusions and recommendations, references and other relevant appendices.

CHAPTER TWO

LITERATURE REVIEW

The chapter gives a review of literature pertinent to the research queries. A review of literature per Gray (2009) "provides up-to-date understanding of the topic, its significance as well as structure. It conjointly helps to spot vital problems and themes that present themselves for additional analysis significantly wherever there are gaps within the current knowledge".

Origin of Cocoa

This study evaluated the growth of cocoa seedlings using different soil and foliar amendments. The genus Theobroma originated in the Amazon and Orinoco basins, and subsequently spread to Central America, particularly Mexico, where it was known and used by the local population. The Olmec and Mayas, and later the Toltecs and Aztecs considered it the "food of the gods". The Maya provided tangible evidence of domesticated cocoa (Asare, 2010).

According to Wood and Lass (1985), cocoa belongs to the family Sterculiaceae, recently, with molecular marker technique; cocoa has been classified to belong to the family Malvaceae (Alvenson, Whitlock, Feller, Bayen & Baum, 1999; Fagbohum, Anibijuwon, Oluwole, & Opeyemi, 2011). Theobroma's genus has twenty two (22) species. However, the only species grown commercially to produce seeds for chocolate making or for the extraction of cocoa butter is Theobroma cacao (Mossu, 1992a).

Cocoa is a small, wide-branching evergreen tree that is native to tropical rainforest areas. It thrives best in soils that are moist, nutrient rich, well-drained and aerated. Cocoa cultivation requires a well-drained, well aerated soil with good crumb structure which contains adequate supplies of water and nutrients. Cocoa seedlings requires nutrients such as nitrogen, phosphorous, potassium, etc. and metabolites (proteins, lipids, carbohydrates) for their growth and development (Gockowski et al., 2004). Cocoa contains important nutrient elements and several minerals including calcium, copper, magnesium, phosphorus, potassium, sodium and zinc (Bearden, Keen, & Steinberg, 2003). Its seeds are used to make cocoa powder and chocolate (Mehta, 2013).

The plant is a native species of tropical humid forests on the lower eastern equatorial slopes of the Andes in South America. Today, cocoa is cultivated globally, and it is grown in the tropical rainforest of Africa, Asia and Latin America. In Ghana, cocoa is grown in the forest areas of the country (Ashanti, Bono, Ahafo, Eastern, Western, Western North, Central, Oti and Volta Regions) where the rainfall is between 1000 and 1500 mm per year. It was introduced into the Southern region of the Gold coast in the mid-19th century (Opoku, Baah, Gyedu-Akoto, Anchirinah, Dzahini-Obiatey, & Cudjoe, 2010).

Cocoa production worldwide and in Ghana

Cocoa is one of the major foreign exchange earners for some African countries, such as Ghana, Cote d Ivoire, Nigeria, and Cameroon. About 70% of the world supply of cocoa originates from Africa, and Ghana is the second largest world producer and supplier of cocoa after Cote d Ivoire (Nkamleu, Nyemeck & Gockowski, 2010). The cocoa sector in Ghana employs over 800,000 smallholder farm families, providing employment, income and a major source of foreign exchange for the country. Out of the 38% contributed by the agricultural sector to foreign exchange earnings in 2008, the cocoa sector constituted 28.5% compared to 5.9% and 3.6% contributed by timber and the non-traditional export sectors, respectively (ISSER, 2008). The farm size is relatively small, ranging from 0.4 to 4.0 hectare with an estimated total cultivation area of about 1.45 million hectares (Anim-Kwapong & Frimpong, 2005).

Cocoa yield in Ghana is about 400 kg of cocoa per hectare, whereas the potential has been estimated to be a 1000 kg per hectare (Barrietos, Asenso-Okyere, & Assuming-Brepong, 2008). The average yield of 400 kg ha^{-1} compared to countries like Cote d Ivoire, Cameroon and Nigeria puts Ghana as performing below its potential (Binam, Gickowsi, & Nklamleu, 2008). This suggests that there is a need to develop interventions that will aim at boosting the productivity levels in cocoa production in the country. In a bid to enhance cocoa yield and productivity, the government of Ghana in consultation with other stakeholders, designed the Cocoa Sector Development Strategy (CSDS) in 1991. Under the strategy, cocoa production was projected to increase from 335,000 tonnes in 1991 to about 500,000 tonnes by 2004/2005 and then to 700,000 tonnes by 2009/2010. In 2010/2011 cocoa production in Ghana increased to 1,000,000 tonnes. However, this level has not been sustainable as it has been fluctuating. It is believed that this increase in the level of cocoa output has been attributed to several interventions including, the Cocoa Hi-tech initiative programme and increase in land size for cocoa production.

Economic Impact of Cocoa Production to Ghana

In 2006, exports of cocoa butter, powder, beans, paste, and waste totalled US$1,241 million, equivalent to more than 33% of Ghana's merchandise exports (WTO, 2008). According to ISSER (2008), cocoa production and marketing accounted for 32.2 percent of export earnings and 8.5% of Gross Domestic Product in 2006, up from 4.9% in 1998 with the European Community being the main export destination for cocoa produced in Ghana (IMF, 2007). In cocoa producing households it is estimated that the mean per capita daily income from cocoa was US$0.42 out of a total income of US$ 0.63 thus indicating a relatively high level of poverty (Barrietos, Asenso-Okyere, & Assuming-Brepong, 2008).

Climate Conditions

The natural habitat of the cocoa tree is in the lower storey of the evergreen rainforest, and climatic factors, particularly nature of soil, temperature and rainfall, solar radiation and humidity are important in encouraging optimum growth. Cocoa requires a hot and wet climate. A mean shade temperature of 27°C, with daily variation less than 8°C, and well-distributed rainfall of at least between 1000–2500 mm, is the ideal climatic conditions for the growth of cocoa. It also needs a well- drained porous soil and a shelter from strong winds and direct rays of the Sun. These conditions are found in the main high forest belt of Ivory Coast and in Ghana, in West Africa and in Brazil. Cocoa is a fairly adaptable crop, and was successfully grown in African countries, though the tree is the native of central and South America (Wood & Lass, 1985).

Temperature

Variations in the yield of cocoa trees from year to year are affected more by rainfall than by any other climatic factor. Trees are very sensitive to a soil water deficiency. Temperature has been related to light use efficiency with temperatures below 24^{o}C having a decreasing effect on the light saturated photosynthesis rate (Hutcheon, 1977). Temperatures below 10^{o}C caused severe inhibition of the photosynthesis rate. The stomata of chilled leaves never opened as wide as stomata of non-chilled plants. Leaf temperature affects stomata resistance, decreasing the resistance upon increasing temperatures. However, since the increases in temperature may often go together with higher vapour pressure deficits (VPD), the effect of VPD may override the effect of temperature (Raja & Hardwick, 1986).

In Ghana, the period of high temperatures when the widest range in the maximum and minimum temperature occurs have been noted to coincide with flushing (Hurd & Cunningham, 1961; Asomaning, Kwakwa, & Hutcheon, 1971).

Rainfall

Rainfall should be plentiful and well distributed through the year. An annual rainfall level of between 1,500mm and 2,000mm is generally preferred. Dry spells, where rainfall is less than 100mm per month, should not exceed three months. Cocoa is highly susceptible to drought and the pattern of cropping of cocoa is related to rainfall distribution. Significant correlations between cocoa yield and rainfall over varying intervals prior to harvest have been reported. It was found that in Ghana a year with high rainfall is followed by a year with a large crop, though the correlation was not applicable in all years (Smellie, 1925; Skidmore, 1929; Brew, 1991). Ali (1969) reported both positive and negative correlations between rainfalls in certain months with the yield of the main crop in Ghana.

The annual total rainfall in the cocoa growing regions of Ghana is less than 2000mm. The rainfall distribution pattern is bi-modal from April to July and September to November. There is a short dry period from July to August during which the relative humidity is still high with over cast weather conditions. There is a main dry season from November to February or March. The four to six months of dry weather results in soil water deficit and since irrigation is not part of the farming system, cocoa seedling mortality is high during the establishment phase. In bearing plants, the existence of the short dry season during main crop pod filling can affect bean size if it is sufficiently severe. In adult plantings, water deficits result in lower yields and an increase in the level of mirid damage (CRIG Annual Report, 1987).

Values defining the limits or adequate soil moisture capacities or available moisture contents for cocoa cultivation during the dry season in Ghana were found to be variable and under field conditions depend on many factors such as: shade, air movement, soil texture and structure, age and vigour of the cacao, volume and distribution of active roots and root depth. In considering the suitability of a soil for cocoa in relation to soil moisture, it is not the quantity of available soil moisture *per se* which is important; it is rather the rate of release of the available water from the soil to the tree which matters and not the intensity of rainfall (Wessel, 1971; Ahenkorah, 1981).

Humidity

A hot and humid atmosphere is essential for the optimum development of cocoa trees. In cocoa producing countries, relative humidity is generally high: often as much as 100% during the day, falling to 70-80% during the night.

Solar radiation and light

The cocoa tree will make optimum use of any light available and traditionally has been grown under shade. Its natural environment is the Amazonian forest which provides natural shade trees. Shading is indispensable in a cocoa tree's early years. Cocoa has a low Light Saturation Point (LSP) of 400 μ E m^{-2} s^{-1} and a low maximum photosynthetic rate (7mg dm^{-1} h^{-1}) at light saturation (Hutcheon, 1981). Galyuon, McDavid, Lopez, & Spence, 1996) indicated that the photosynthetic rate of the crop decreases if the photosynthetic apparatus is exposed to light intensities exceeding 60% of full sunlight that is 1800 μ mol m^{-2} s^{-1} while prolonged exposure to high light intensities damages the photosynthetic mechanism of the leaves (Raja & Hardwick, 1988). Low light intensities however suppress flower production with light levels less than 1800 hours $year^{-1}$, having a considerable depressing effect on production (Asomaning, Kwakwa, & Hutcheon, 1971).

It is well established that, in general, where soil nutrients, water and temperature are not limiting and losses from pests and diseases can be avoided, crop growth and yield are dependent on the total solar radiation intercepted during the growing season (Monteith, 1978). Trials in West Africa have shown that potential yields of cocoa can be doubled by removing permanent shading (intercepting 30-50% incident radiation) provided fertilizers are applied (Lechenaud & Mossu, 1985).

Nature of Soils

The best soils in terms of high cocoa production tend to have an average pH 5.6-7.2 in 1:2.5 water: soil, C/N ratio between 10-12: organic carbon not less than 3%, base exchange capacity of 3-15 cmol kg^{-1} available P greater than 20mg kg^{-1} in the 0-5 cm and 15 mg kg in 0-20 cm layer (using buffered 0.002N H_2SO_4 extractant), exchangeable K not less than 0.25 cmolc kg^{-1}, (Ca + Mg) about 8-13 $cmol^+$ kg^{-1} and no Aluminium in the exchange complex (Ahenkorah, 1981). Adu and Mensah-Ansah (1969) categorized soils in Ghana into cocoa suitability soils based on textural and depth analyses. In this categorization, the model profile of good cocoa soils are deep and characterized by well drained non-gravelly top soil over sandy clay loam layer which usually contains both iron oxide concretions and quartz gravels. This layer overlies sedentary mottled clay, which merges with the incompletely weathered parent material (Ahenkorah, 1981).

Soils carrying cocoa in Ghana are classified as follows: unsuitable, suitable and highly suitable (Ahenkorah, 1981). The unsuitable soils are highly desaturated ferrallitic soils, primarily tropudults and paleudults (Forest Oxysols and Oxysol-Ochrosol intergrade). These soils cover the South of the Western Region. It is on these soils that the moves to extend the area planted in recent years have taken place. Without fertilizer application, their lack of available minerals results in limited yields and to premature tree aging (for trees grown in full sunlight, yields tend to fall around year 10 onwards) (Adu

& Mensah-Ansah, 1969; Ahenkorah, 1981). The suitable soils are moderately desaturated ferrallitic soils (dystropepts/Forest Ochrosols). These are primarily found in the old cocoa growing areas of Eastern and Ashanti regions. It is possible, without fertilizer application and with light permanent shading to achieve potential yields of around 1500 kg per hectare over fifteen years or more (Adu & Mensah-Ansah; Ahenkorah, 1981).

The highly suitable soils are only slightly desaturated ferrallitic soils (tropical eutrophic brown soils/ Forest Ochrosol-Rubrisol intergrade) with a high exchange capacity hence a better response to mineral fertilizers. These are generally well-drained and deep soils occurring in limited areas in Ashanti and in the North of Western Region (Adu & Mensah-Ansah, 1969; Ahenkorah, 1981).

Figure 1 show the major soil groups within the cocoa growing regions of Ghana. Notice the relationship between forest types and the distribution of soil groups.

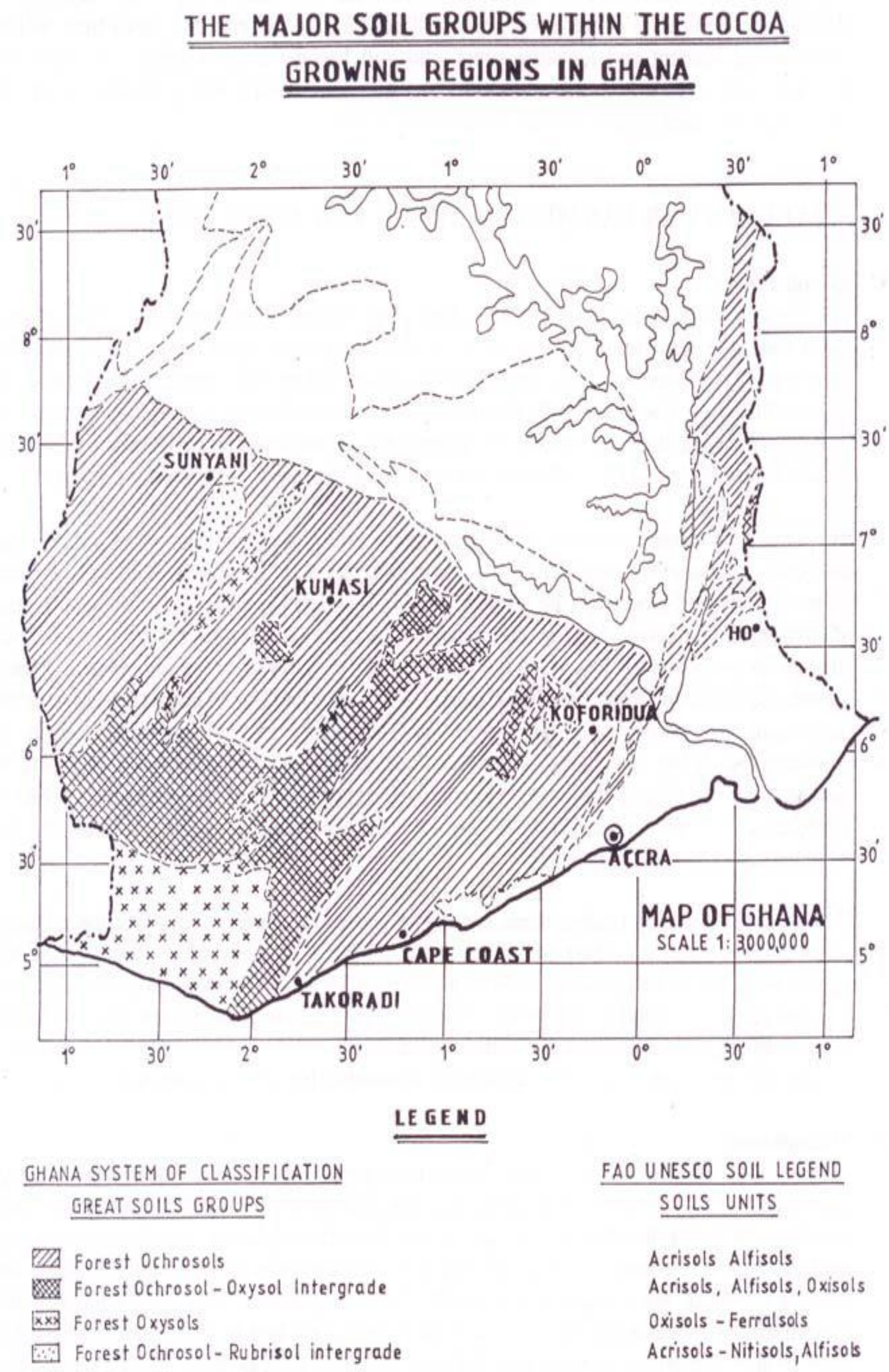


Figure 1: Major soil groups within the cocoa growing regions of Ghana

Soil Requirement

Cocoa can be grown on a wide range of soils provided they are fairly deep and well-drained. Loamy soils rich in iron and potassium are ideal but light clays are also suitable. The heaviest crops come from cocoa grown on newly cleared virgin equatorial forest soils with high humus content but manuring in long-established groves enhances the yields. Clay loam and sandy loam are the best soils for cocoa production. Meanwhile, cocoa does not endure low soil fertility compared to oil palm and rubber. Cocoa plant flourishes in a variable soil pH which may range from acidic pH 5.0 to very alkaline pH 8.0 (Mossu, 2001). However, the best cocoa growing soils are close to neutral pH 7.0 with the optimum pH being slightly acidic of pH 6.5. The depth of the soil must be at least 1.5m deep, have good water retaining ability, be well aerated and have good drainage (Mossu, 2001). The soil structure must be homogenous as possible for easy penetration of the plant's roots. A soil with sandy clay texture is always preferable in high rainfall areas than sandy soil.

Soil physical condition

Cocoa needs a soil containing coarse particles and with a reasonable quantity of nutrients, to a depth of 1.5m to allow the development of a good root system. Below that level it is desirable not to have impermeable material, so that excess water can drain away. Cocoa will withstand waterlogging for short periods, but excess water should not linger. The cocoa tree is sensitive to a lack of water, so the soil must have both water retention properties and good drainage.

Chemical properties of the topsoil are most important, as the plant has a large number of roots for absorbing nutrients. Cocoa can grow in soils with a pH in the range of 5.0-7.5. It can therefore cope with both acid and alkaline soil, but excessive acidity (pH 4.0 and below) or alkalinity (pH 8.0 and above) must be avoided. Cocoa is tolerant of acid soils, provided the nutrient content is high enough. The soil should also have a high content of organic matter about 3.5%. Soils for cocoa must have certain anionic and cationic balances. Exchangeable bases in the soil should amount to at least 35% of the total cation exchange capacity (CEC), otherwise nutritional problems are likely. The optimum total nitrogen / total phosphorus ratio should be around 1.5.

Soil Amendment for Sustainable Cocoa Production

Providing farmers with technologies to maintain soil health would enable sustainable cocoa production, maintaining the long-term viability of cocoa farms and thus removing the driver for shifting cultivation. This would help the Government and cocoa sector to meet their commitment to grow more cocoa on less land, and not at the expense of tropical forests that represents major stock of carbon.

Global Trend of Fertilizer Usage

In 2006, the normal utilization of fertilizer in Africa was 8 kg-ha^{-1} contrasted with 73 kg-ha^{-1} in Latin America and 135 kg-ha^{-1} in Asia (MOFA, 2008). Considering the requirement for higher fertilizer use in Africa, the Africa Fertilizer summit was held in Abuja (Nigeria). In 2006, under the support of the African Union (AU), New Partnership for African Development (NEPAD) and the administration of Nigeria the Abuja Declaration on Fertilizer for African Green Revolution, in which AU Member States set out to expand encouraging access to manure by farmers and to raise compost use to a normal of 50 $kg\text{-}ha^{-1}$ by 2015 (AU, 2006). Numerous administrations around the globe have executed compost appropriation projects to raise the level of fertilizer use by small holder agriculturists (Crawford *et al.*, 2006; Morris, Kelly, Kopicki, & Byerlee, 2007).

Fertilizer Application in Production of Cocoa in Ghana

According to the Cocoa Research Institute of Ghana (1987), yield of cocoa could be increased by 30% by applying fertilizer. However, it is uneconomical to apply fertilizer to young cocoa plants. It is recommended that fertilizer be applied to plantations 10 years and above at two year intervals. For the use of fertilizer to be effective, it must be done with good management practices such as timely weed control, removal of shades and removal of mistletoes. In the 1980s, the Cocoa Research Institute of Ghana (CRIG) recommended a single fertilizer formula, called Asaase Wura, for the whole country. This formula contains N– 0%, P_2O_3–22%, K_2O-18% and small amounts of calcium, sulphur and magnesium (Appiah, Sackey, Ofori-Frimpong, & Afrifa, 2000). In most cocoa producing countries, cocoa trees are over 50 years old, and the cocoa industry is now facing problems of aging trees and depleted soils because of continuous cropping with little or no added inputs (Hanak-Freud, Petithuguenin, & Richard, 2000). In 1994, the Ghana Cocoa Board estimated that about 72% of farmers in Ghana produced less than

384 kg of cocoa ha^{-1}year-1 without the use of fertilizers, while in the same period; yields of 1,300 kg ha^{-1}.year-1 were reported from smallholder farmers who applied fertilizers (Appiah, Sackey, Ofori-Frimpong, Afrifa, 1997). Cocoa production has increased regularly since 2004 (Ruf, 2007). Teal, Zeitlin, & Maamah, 2006) reported that during the same period, farmers increased the recommended amount of fertilizer from 22 to 230 kg ha^{-1}. This suggests that farmers appreciate the use of fertilizers as a way of increasing the profitability of their cocoa plantations.

Fertilizer and its Quality on Cocoa Production

Fertilizers are substances that supply plant nutrients or amend soil fertility and are applied to increase crop yield or quality, as well as sustain soil capacity for future crop production (IFA, 1992). Nutrient management is the key issue in sustainable soil fertility. The N, P, K fertilization aims not only for a high economic return of the investment through optimized yield and quality, but also for minimum environmental hazards. The basic concept underlying integrated plant nutrition systems is the maintenance and possible increase of soil fertility for sustaining enhanced crop productivity through optimal use of all sources of plant nutrients, particularly inorganic fertilizer, in an integrated manner and as appropriate to each specific ecological, social and economic situation. Much research has established the importance of fertilizers in increasing the fertility of soil and in influencing its productivity. It has been observed that applying fertilizers causes many changes in the soil, including chemical changes that can positively or negatively influence its productiveness (IFA, 1992).

Influence of Organic and Inorganic Fertilizers on Soil Fertility

Fertile and well-managed soils form the basis for efficient crop production. The three most important elements needed for crop productions are nitrogen (N), phosphorus (P) and potassium (K). Nitrogen is a vitally important plant nutrient and is the most frequently deficient of all nutrients. There is an apprehension that the use of chemical fertilizers over the years might be impairing the soil fertility. In continuous cropping, use of imbalanced nutrients (N or NP alone) through inorganic fertilizers without organic manure cannot sustain the desired level of crop production (Tiwari, Dwivedi, & Dikshit, 2002). Soil amendment with organic material could play an important role in plant nutrition in the organic agriculture movement as well as under the integrated soil fertility systems since the sole use of mineral fertilizer has been reported to lack the capacity to sustain productivity under the continuous intensive cropping system found in most commercial farms (Benbi, Biswas, Bawa, & Kumar, 1998). Long term use of mineral fertilizer without organic amendments has been reported to result in reduction in soil base saturation and increased acidity over (Hills, Miller, & Miller, 2000), while the application of organic material has been reported to improve soil physical properties, nutrient supply, crop yield (Yaduvanshi, 2003) and soil microbial activities (Nath & Yadav, 2011). Agriculture farm based product viz. farm yard manure (FYM), vermicompost, poultry manure and other organic resources play a dominant role in soil fertility management (Palm, Gachengo, Delve, Cadisch, & Giller, 2001). Manure product has a lower C/N ratio, higher protein: organic C ratio, and higher levels of N, which indicates that the manures are more suitable for soil amendment use (Goyal, Mishra, Hooda, & Singh, 1992). In containerized production systems, manures used as an alternative soil amendment could help reduce several problems associated with the use of conventional synthetic fertilizer such as excessive leaching loss of nutrients and salinity-induced plant stress. In addition manures can improve soil porosity, and thus provide a better root growth medium (Hala, Chaoui, Zibilske, & Tsutomu, 2003). Soil nutrients and enzyme activities respond much more quickly to the changes in soil management practices as compared to total soil organic matter (Doran, Sarrantonio, & Leibig, 1996). Therefore, measurement of nutrients release provides a sensitive indication of organic matter turnover. This results in consumption of C, N and other nutrient elements by the microbes and their subsequent release for plant use. This depicts the known microbial immobilization and mineralization of nutrients for plant use (Fatunbi & Ncube, 2009). The duration of this phenomenon in a system will either allows or debars the utility of organic materials as source of plant nutrients in the short run. The duration is known to be affected by the chemical characteristics of the organic materials viz., C: N, Lignin, polyphenols, total N and climatic variables such as moisture, temperature, relative humidity etc., (Bayala, Mandob, Teclehaimanotc, & Ouedraogoa, 2005). Thus, there is a need to determine the immobilization/mineralization time lag, when applying organic materials. This will provide information that could be used to synchronize the time of organic materials and fertilizer application with that of plant nutrient need.

Soil, organic and inorganic amendment

The optimum total nitrogen/total phosphorus ratio should be around 1.5. The best soils in terms of high cacao production tend to have an average pH 5.6-7.2 in 1:2.5 water: soil, C/N ratio between 10-12, organic carbon not less than 3%, base exchange capacity of 3-15 me/100 g soil available P greater than 20 ppm in the 0-5 cm and 15 ppm in 0-20 cm layer (using buffered 0.002N H2SO4 extractant), exchangeable K not less than 0.25 /100 g soil, (Ca + Mg) about 8-13 me/100 g soil and no aluminium in the exchange complex (Ahenkorah, Halm, Appiah, & Akrofi, 1982).

An alternative attempt is to use topsoil but such soils are mostly deficient in P, K, Ca, Mg and ECEC (Rhodes, 1995). Poor growth of cocoa seedlings in the nursery has been ascribed to the use of unsuitable potting media and also the problem of getting adequate quantities of fertile topsoil for potting cocoa (Donkor, Henderson, & Jones, 1991; Ofori-Frimpong, Afrifa, & Acquaye, 2006). Foliar fertilizers have multiple advantages. These include efficient and timely method of applying and enhanced nutrient utilization. The use of inorganic fertilizers is the most effective and convenient way to improve the fertility of nutrients poor soils. Inorganic fertilizers are known to contain readily available plant nutrients which are released to plants rapidly after application. The work by Gockowski et al., 2004) indicated that cocoa seedlings need nitrogen, phosphorus, potassium and metabolites such as proteins, lipids, carbohydrates for their growth. Application of fertilizers significantly ($p<0.05$) influenced seedling girth with the foliar NPK 15-8-33+TE recording the biggest stem (Arthur, et al., 2019). Foliar fertilizer treatments gave significantly ($p<0.05$) tallest plant height compared to the

Green grow and the inorganic NPK fertilizer treatments (Arthur et al., 2019). Moyin-Jesu (2007) reported the nutrient superiority of organically amended fertilizers compared to the ordinary forms of the materials. Arthur et al. also found an improvement in soil chemical properties following the application of Municipal Solid Waste compost to less fertile topsoil.

Influence of Soil Fertilization on Cocoa Seedling Growth

Cocoa production in Ghana is limited by soil nutrient depletion after many years of cultivation. The establishment of cocoa farms normally begins with the raising of seedlings in nurseries using topsoil from refuse dumps known as 'Black soil'. This type of soil cannot effectively support cocoa seedling growth in the nursery currently, because it is basically made up of non-degradable materials (Rhodes, 1995). An alternative attempt is to use topsoil but such soils are mostly deficient in P, K, Ca, Mg and ECEC (Rhodes, 1995). Poor growth of cocoa seedlings in the nursery has been ascribed to the use of unsuitable potting media and also the problem of getting adequate quantities of fertile topsoil for potting cocoa (Donkor, Sarrantonio, & Liebig, 1991; Ofori-Frimpong, Afrifa, & Appiah, 2006). Under the current cocoa rehabilitation programme in Ghana, most farmers who prepare nurseries from seed pods collected from the Seed Production Division of COCOBOD use different types of soils from their farms for filling the polybags. These soils are low in fertility, therefore impact negatively on the growth of cocoa seedlings. There is the need to look for ways of improving the growth of cocoa seedlings in the nursery, and young cocoa after transplanting in the field. One such way is to apply foliar fertilizers to seedlings in the nursery and after transplanting. The work by Gockowski et al. (2004) indicated that cocoa seedlings need nitrogen, phosphorus, potassium and metabolites such as proteins, lipids, carbohydrates for their growth. Thus it is important that young nursery seedlings and transplanted seedlings are in optimal condition as far as their nutrient and energy status are concerned. Though, there are studies reported on utilization of organic fertilizers especially cocoa pod husk for raising cocoa seedlings, there is limited research information on how different fertilizers especially foliar fertilizers can effectively be utilized to boost the growth of cocoa seedlings in nutrients poor soils in Ghana (Oppong, Ofori-Frimpong, & Fiakpornu, 2008).

Nitrogen is one of the earth's most abundant and mobile nutrients. It is part of every plant cell. Nitrogen is part of chlorophyll which gives plants their green colour. Plants need nitrogen to produce essential molecules such as proteins and chlorophyll. Air contains more molecular nitrogen than any other gas. The air we breathe contains thirty-seven thousand tons (78% by volume) of elemental nitrogen over each acre of the earth's surface and it is the origin for all other nitrogen sources (Posch, KAmAri, Forsius, Henriksen, & Wilander, 1997).

Carbon is a key component of Soil Organic Matter (SOM) and has major impact on the availability of other nutrients in soils. Baldock and Skjemstad (1999) defined SOM as "all organic materials found in soils irrespective of origin or state of decomposition. Zhang, Feng, & Declerck, 2018) defined SOM in a broad sense to include above and below ground macro-morphologically identifiable plant residues (primary resources), residues from soil animals and microorganisms (secondary resources), dissolved organic matter, root exudates and morphologically unstructured, macromolecular humid compounds.

Phosphorus, unlike nitrogen, is very immobile in the soil and moves primarily as soil particles are moved. It is lost from the soil through plant removal and soil erosion. Phosphorus uptake by plants is about one-tenth that of nitrogen and one-twentieth that of potassium (Brady & Weil, 1999). This element is in high need by young plants of seedlings. Phosphorus performs the following functions in that it encourages blooming and root growth (Parker, 2004), helps in the transformation of solar energy into chemical energy, is involved in the formation of all oils, sugars, starches, etc., affects rapid growth and is an essential part of the process of photosynthesis.

Root Shoot Ratios, Optimization and Nitrogen Productivity

It is a standard assumption in plant ecology that plants respond to their environment in such a way as to optimize their resource use (Bloom, Chapin III, & Moonery, 1985). One expression of such an optimization is the allocation between shoots and roots in response to nutrient availability. In general, when nutrient availability increases, plants allocate relatively less to their roots, which is consistent with a resource optimization hypothesis as increasing nutrient availability means that less effort is required to acquire this resource. Exceptions to this rule, when K, Mg or Mn are limiting (Ericsson, 1995), can be recast into the resource optimization hypothesis. Deficiencies of these elements lead also to a shortage of carbohydrates, which signifies to the plant that the allocation to light acquisition is sub-optimal.

Several models have been developed to explain the mechanisms behind the root: shoot allocation (See reviews by Wilson, 1988; Agren & Wikström, 1993; Cannell & Dewar, 1994). All models are based on a carbon balance, but some additional constraints are required. Two general routes can then be followed. First, some plant property is optimized, which, in practise, always turns out to be the relative growth rate (Johnson & Thornley, 1987; Hilbert, 1990; Thornley, 1995). Secondly, a sink strength depending either on nitrogen concentration (Ågren & Ingestad, 1987; Ingestad & Ågren, 1991) or on carbon and nitrogen substrate concentrations (Thornley, 1972, 1995, 1998) is added. The problem with the latter group of models is that they require phenomenological formulation of plant properties (nitrogen productivity, substrate utilization rates or transport rates) and, therefore, only show consistency between plant properties without explaining them in terms of some underlying principle. Formulations derived by maximizing the relative growth rate give, in general, qualitatively satisfactory results but quantitative tests seem to be lacking. One reason for this is the problem of independently estimating all the necessary parameters required for testing the predictions; in particular the relationship between net assimilation rate and plant nitrogen concentration has to be specified.

In this paper, a relationship between the shoot fraction (f_S) and plant nitrogen concentration (c_N) will be derived by maximizing the relative growth rate. The problem of the arbitrariness in the relationship between assimilation rate and plant nitrogen concentration will be avoided. Instead the strong empirical, linear relationship between relative growth rate and plant nitrogen concentration (Ågren & Wikström, 1993) will be used to derive the assimilation rate as a function of plant nitrogen concentration. The final relationship, $f_S(c_N)$, will then have only one or two free parameters that will be adjusted when comparing predictions with experimental results.

CHAPTER THREE

MATERIALS AND METHODS

This chapter presents the techniques and procedures employed to conduct the study. The choice of research design, data collection sources and instruments, the sampling techniques, key data variables and their measurement and the data processing, analysis and reporting framework have been explained in this chapter.

Methodology

This study evaluated the growth of cocoa seedlings using different soil and foliar amendments. It searches for an alternative means of raising healthy seedlings at the nursery that will accelerate seedling growth is what this trial investigates.

Experimental Site

The study was carried out at the Cocoa Research Institute of Ghana Main Nursery in Tafo in the Eastern Region of Ghana.

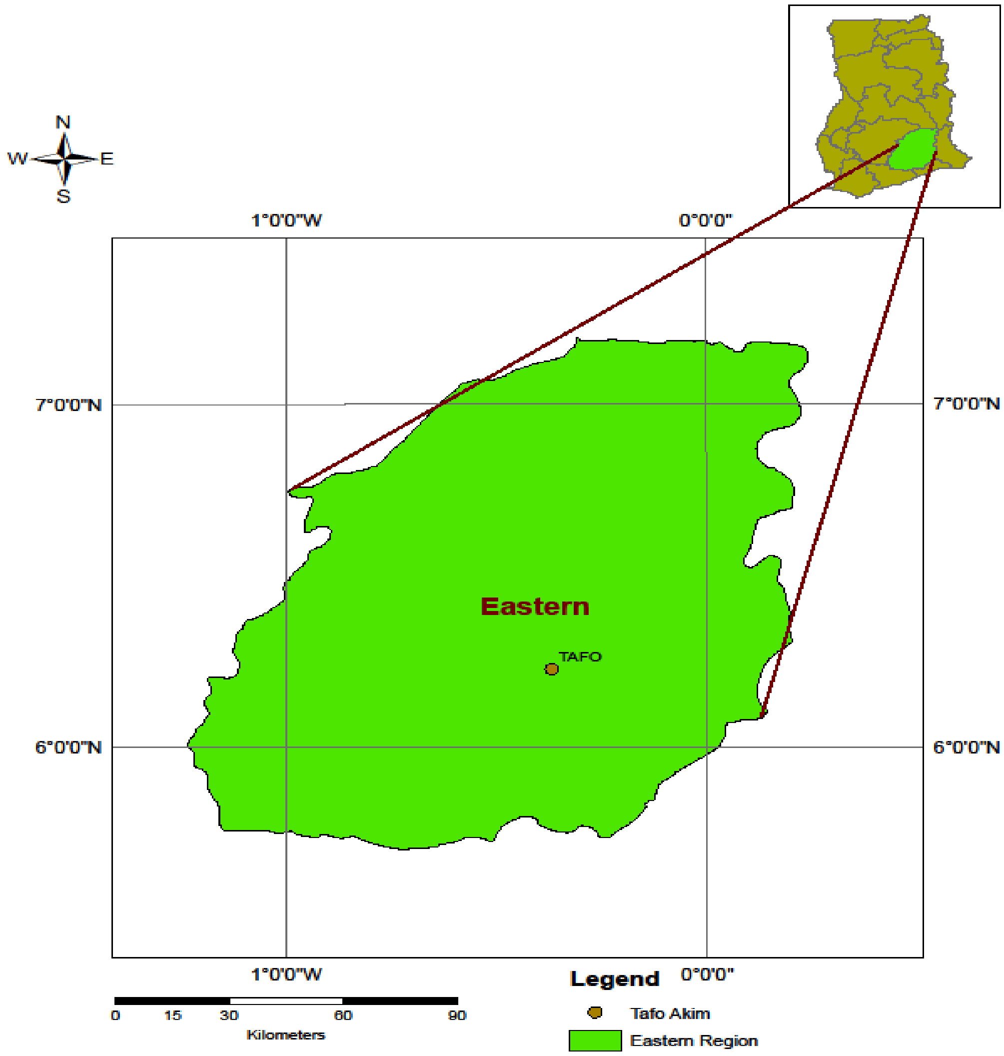


Figure 2: Location of the study

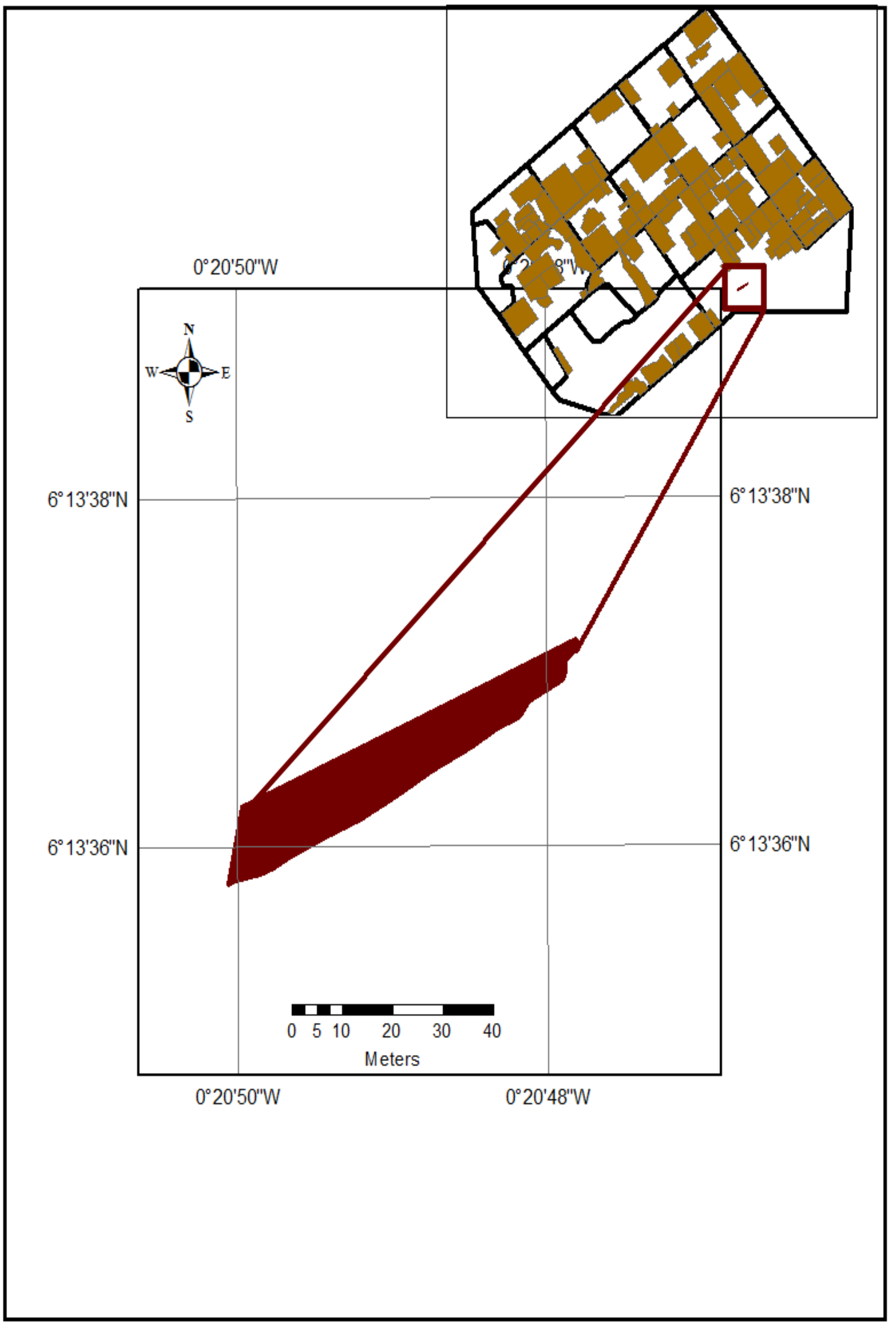


*Figure 3***:** The research site (Cocoa Research Institute of Ghana)

Weather Condition during the Experimental Period

Rainfall

Mean daily rainfall recorded during the experimental period was 22.9 mm (January to July 2020). The highest daily rainfall was recorded was 75.0 mm whiles the month of January recorded no rainfall. March recorded highest mean daily rainfall of 444.6 mm. February, April, May, June and July recorded 7.0, 29.9, 32.2, 26.8 and 20.0 mm respectively. The area is characterized by a bimodal type of rainfall with peak season in June and October. It has an annual rainfall of 1700 mm. The first rainy season is from May to June, while the second season is from September to October, with little variations.

Temperature

Highest temperature recorded during the experimental period was 38.0 ^{0}C whiles the lowest was 27.5 ^{0}C. The mean daily temperature for experimental period was 33.1^{0}C.

Relative humidity

Humidity, which was high throughout the year varies between 70 - 80 percent at maximum and minimum of 62.5 – 44.2 percent. With relief and drainage, the Akim Tafo district is generally characterized with slope, hilly and rugged with undulating landforms and patches of mountains. Tafo is located within Latitude 06^o 13 N, Longitude 00^o 22 W, and has an altitude of 198 m above sea level with a total land area of 4, 3027 km.

Vegetation

The predominant vegetation type found in the Abuakwa North district is semi-deciduous forest with well drained forest ochrosols which can support cash crops like cocoa, cola nuts, citrus, rubber and other fruits. Food crops like maize, cassava, cocoyam, plantain and vegetables also do very well in the district.

Site Preparation

Nursery

Cocoa nursery is a place where cocoa seedlings are raised for transplanting to the field at the appropriate time. Nursing cocoa begins in November and December. This timing would help meet the rains at time of transplanting to the field. The success of a cocoa farm to a larger extent would depend on a good planting material. Cocoa farm can also be established directly by planting in-situ or direct seedling.

Type and size of bags used to nurse the seedlings

Soil was dug from 0-15cm depth from a field at the CRIG. Soil samples were collected at random and composited. The soil has been classified as Ferric-Lixisols by USDA (2014) and belongs to the WACRI series according to the Ghanaian system of classification.

Soils sampled were sent to the laboratory for physical and chemical analyses and used as baseline data. Soils for nursery bags were sieved through an 8 mm wire mesh before bagging. Nursery bags were first perforated at the bottom with a perforator to create a 4 cm^2 hole to facilitate drainage of excess water before filling with the top soil. Poly bags used were of dimension 18 cm× the 25 cm. Hand trowel was used to fill the poly bags. Each nursery bag was filled with 3 kg air dried soil. Each treatment consisted of twenty bags. In the cocoa industry, research has concluded that a black polybag of size of 17.5

x 25 cm (containing 3 kg topsoil at field capacity) was suitable for maintaining seedlings in the nursery up to 6 months before transplanting (Opoku-Ameyaw,Baah,Gyedu-Akoto,Anchirinah,Dzahini-Obiatey&Cudjoe,2010).

All the polythene bags were then arranged on thick polythene sheet to prevent the growth of the roots into the ground for possible uptake of nutrients. Each polythene bag was sown with two mixed hybrid cocoa seeds which were thinned out to one seedling per polythene bag at 20 days after sowing. The foliar fertilizer was applied every fortnight, with a knapsack sprayer applied on the leaves and the granular fertilizer was dissolved in 100 mls of water per seedlings and applied to the soils with a measuring cylinder.

As recommended by Opoku-Ameyaw and Appaih (2000), all CRIG recommendations on agronomic practices were routinely carried out on all treatments. The seedlings were kept under a shade and watered as and when necessary to keep the moisture content of the soil at field capacity. Weeds were removed by hand picking. Confidor 200 O-TEQ, a systemic insecticide was applied quarterly to the seedlings at a rate of 30 mL in 15 L of water using a pneumatic knapsack sprayer to prevent damage by insect pests. Sampling started one month after seedling emergence and continued at monthly interval for seven 6 months.

Experimental Design

Randomized Complete Block Design (RCBD) with nine treatments replicated three times. Four different types of fertilizers were used in this study. These include organic liquid, organic granular, inorganic liquid and inorganic granular fertilizers applied as foliar and to soil.

The organic fertilizers used were the Organic foliar-Green OK and organic granular-Elite fertilizer. The inorganic fertilizers used were the Inorganic foliar–Sidalco and Inorganic granular NPS. The Randomized Complete Block Design is a standard design for agricultural experiments where similar experimental units are grouped into blocks or replicates. It is used to control variations in an experiment by accounting for spatial effects in field or greenhouse.

Treatments

T1-Inorganic liquid Fertilizer-Sidalco 0.42 ml per seedling (bag)

T2- Inorganic liquid Fertilizer-Sidalco 0.84 ml per seedling (bag)

T3-NPS Inorganic Granular Fertilizer 0.6 g per seedling

T4-NPS Inorganic Granular Fertilizer 1.2g per seedling

T5-Green OK (Organic liquid fertilizer 0.42 ml per seedling

T6-Green OK (Organic liquid fertilizer 0.84 ml per seedling

T7-Elite (Organic granular) 4.5g per seedling

T8-Elite (Organic granular) 9.0 g per seedling

T9-Control

Table 1 - *The Chemical Properties of the Treatment Materials*

Treatments	% Nitrogen(N)	Phosporus (P)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)	Zinc(Zn)
T1	10	10	10	-	-	-
T2	10	10	10	-	-	-
T3	21	14	11	-	-	-
T4	21	14	11	-	-	-
T5	0.106	0.017	0.303	0.059	0.975	0.059
T6	0.106	0.017	0.303	0.059	0.975	0.0.59
T7	2.08	5.25	3.358	-	-	-
T8	2.08	5.25	3.358	-	-	-
T9	-	-	-	-	-	-

Source: Field data (2020)

Sidalco 10:10:10 foliar fertilizer contains 10 % Nitrogen, 10 % Phosphorus, 10 % Potassium providing an external source of the nutrients for treatments 1 and treatment 2. Level of fertilizer in treatment 2 is twice that of level 1. Treatments 3 and treatment 4 were applied with inorganic granular fertilizer called N-P-S, which is a newly validated fertilizer from Council for Scientific and Industrial Research (CSIR), which contain 14 % nitrogen, 31 % Phosphorus and 9% Sulphur used for T3 and for T4. Treatments 5 and 6 were organic foliar fertilizers called Green OK which contains 0.106 % Nitrogen, 0.017% P and 0.303 % K, M 0.0595 C 0.0975%, and Zinc 0.059% with P_2O_5, 0.038%,K_2O 0.366,MgO 0.098% and CaO 1.365%. Treatments 7 and 8 were organic granular called Elite fertilizer containing 2.083 % N, 5.25% P and 3.358% K. Treatment 9 was the control with no fertilizer amendment.

Data Collection

Growth data

Growth parameters specifically height and stem diameter were taken on each treatment with the aid of a standard metre ruler and digital callipers respectively. Numbers of leaves were counted. Every month, three seedlings from each treatment were harvested to measure the dry matter and nutrient contents.

Dry matter was taken by tearing apart the polythene bag containing each of the sampled seedlings and the whole seedling thoroughly washed with water with the roots intact. The seedlings were partitioned into shoots and roots after which the fresh weights and root volumes were taken.

Root volume was determined by water-displacement method (Burdett, 1979). This was done by placing roots into a graduated cylinder containing 100 ml water, then, before-and-after immersion difference of volume was calculated using the equivalence of 1 mL equals to 1 cm^3. All plant parts were dried to a constant weight at 75 ^oC for 3 days for the dry weights. The dry weight of each component was determined with a top loading metre balance. The dry plant parts were ground and sieved with 1 mm mesh size sieve and subsequently analysed for nitrogen, phosphorus, and potassium contents.

Data collection instruments

Standard ruler for taking height and root length in cm. Digital calliper used for taking the stem girth in mm. Digital weighing scale for taking fresh and dry weight of samples. Measuring cylinder was used for taking root volume. Pencil, eraser, note book and pen for taking records.

Soil Processing and Analysis

Soil samples were air-dried, sieved, and analyzed in the laboratory using standard techniques. Laboratory analyses were carried out on the soils to ascertain their nutrient levels using standard methods. Nutrients including nitrogen, potassium and phosphorus, calcium and magnesium were determined. Determination of the pH of the soil mass is essential. For healthy plants to grow, the acidic and basic nature of soil must be known.

Soil pH

Soil pH was determined in a 1:2.5 soil-water suspension using a glass electrode and pH meter (ISRIC, 1992).

Determination of soil pH using glass electrode / pH meter, and 1:2.5 Soils - water suspension

i. 10.0 g of air-dried soil samples were weighed into 100 ml beakers.
ii. 25 ml of distilled water were added to the samples.
iii. The beakers containing the samples were stirred and left to stand for 30 minutes. (This was to make sure that the hydrogen ions have been extracted).
iv. Before taking any measurements or readings, the pH meter was standardized as follows:
v. A buffer solution of pH 4 was measured by dipping the electrode into the solution and adjusting the meter to read the pH of 4.
vi. The electrode was rinsed with distilled water and wiped gently with tissue paper.

vii. A buffer solution of pH 7 was measured in the same manner after which the electrode was rinsed again with distilled water and wiped gently.

The test samples were then measured, making sure the electrode dipped into the solution properly, after which the pH of the samples read on the pH meter and recorded

Total nitrogen

Total Nitrogen was determined using the Kjeldahl method of Bremner (1965).

Determination of total nitrogen in soils by Kjeldahl method

i. 2.5 g of air-dried soil samples were weighed into smaller digestion tubes, after which about 0.5 g of catalyst was added to the samples in the tubes.

ii. 12 ml of conc. H_2SO_4 were added to the samples under fume chamber.

iii. The tubes were put in a digestor under fume chamber, and the samples were digested for 2 hours at 350 ^oC (the temperature and time were increased when samples were not well-digested). Well-digested samples were either white or colourless.

iv. The digested samples (digests) in the tubes were allowed to cool in a fume chamber until there were no fumes evolving.

v. The smaller tubes containing the digests were washed and rinsed about three times with distilled water into bigger tubes for distillation.

vi. The distilled samples (distillates) which contained the ammonia compounds were then collected in receiver flasks containing boric acid and titrated with 0.02N H_2SO_4 till just a colour change was observed (from green to blue).

vii. The Percentage Nitrogen in the samples was then calculated using the formula below:

$$\% \text{ Nitrogen} = \frac{\text{Titre value of sample (ml)} \times \text{Normality of acid (0.02)} \times 1.401}{\text{Weight of sample (g)}}$$

Catalyst:1:5:25 g Selenium (Se), Copper sulphate ($CuSO_4$), Potassium sulphate (K_2SO_4) ratio, prepared by grinding separately 4 g Se, 20 g $CuSO_4$, and 100 g K_2SO_4, and put together in a catalyst container.

Available phosphorus

Available Phosphorus (P) was determined by Truog method (1930) and colorimetrically on Spectrophotometer. Available Phosphorus was determined by Truog method (1930) and colorimetrically on Spectrophotometer.

Determination of available phosphorus in soils using 0.2 normal sulphuric acids (0.2n H_2so_4) as extraction solution / extractant (Truog method)

i. 5.0 g of air-dried soil samples were weighed into shaker bottles.

ii. 100 ml of 0.2N H_2SO_4 were added to the samples in the shaker bottles, which were then, shook for 2 hours on a mechanical shaker.

iii. The shook samples were filtered through Whatman No. 42 filter papers into 100 ml volumetric flasks.

iv. 10 ml aliquot of the sample solutions in the 100 ml volumetric flasks were pipetted into 25 ml volumetric flasks.

v. 4 ml of 'Reagent B' were added to the sample solutions, followed by distilled water to the 25 ml mark and then shake by hand to mix well. Blank solutions were also prepared with 4 ml Reagent B and distilled water.

vi. UV Visible Cecil Spectrophotometer (CE 7400 model) was calibrated using Phosphorus Standards of known concentrations at a wavelength of 882 nm.

vii. Upon blue colour development, absorbance readings of the samples were taken on the spectrophotometer at the same wavelength.

viii. The absorbance readings (nm) were then used to calculate for the Available Phosphorus in the samples using the formula below:

Available Phosphorus (μg / g) = <u>(Absorbance / G.F) x D.F x Volume of extractant (100 ml)</u>

Weight of soil (5.0 g)

Where; G.F is Graph Factor = <u>∑ of Absorbance readings of Phosphorus Standards</u>

∑ of Concentrations of Phosphorus Standards

D.F is Dilution Factor = <u>Volume of volumetric flask used (25 ml)</u>
Volume of aliquot used (10 ml)

Exchangeable Bases

Exchangeable acidity was extracted with 1.0 N ammonium acetate and 0.1 *M* Cl extract respectively and the filtrates analysed on atomic absorption spectrophotometer.

Exchangeable Cations (Bases) commonly found in soils and which are of particular importance to cocoa cultivation are Potassium (K), Magnesium (Mg), and Calcium (Ca). These are also basic essential macronutrients which cocoa and all other crops require in sufficient amounts from the soil for their growth, survival and development. Exchangeable Bases were determined by leaching the samples with Ammonium acetate solution (Hanway & Heidel, 1952). The leachates were then analysed on Atomic Absorption Spectrometer for Potassium, Magnesium and Calcium concentrations.

Determination of exchangeable bases in soils by ammonium acetate method of Hanway and Heidel

The Exchangeable Bases analysed were Potassium, Magnesium, and Calcium. The procedure used is as follows:

i. 5.0 g of air-dried soil samples were weighed into shaker bottles.
ii. 25 ml of 1Molar Ammonium acetate (1M NH_4OAC) solution were added to the samples in the shaker bottles, which were then, shook for 10 minutes on a mechanical shaker.
iii. The shaken samples were filtered through Whatman No. 42 filter papers into 50 ml volumetric flasks.

iv. The sample solutions (filtrates) were analysed for the concentrations of the various elements on the Atomic Absorption Spectrometer (Spectra AA 220 FS model, Varian Brand)

The extraction solution was prepared by weighing 77.08 g of solid NH_4OAC into a 1 litre beaker and completely dissolved with distilled water. The solution was then poured into a 1 litre volumetric flask and made to volume with distilled water. The flask was labelled.

Soil particle size and texture

Soil texture is a measure of the relative proportions of the different size classes of sand, silt and clay, which are the three primary soil separates/particles. Textural Class is a name given to soils based on the relative proportions of the three primary particles. Soil texture influences soil structure, fertility, water and nutrient holding capacity, and also affects certain physico-chemical processes in the soil. The relative proportions of Sand, Silt and Clay were determined by the Hydrometer method of Bouyoucos (1951). Subsequent estimation of Textural Class was done using the USDA Textural Triangle.

Mechanical analysis (particle size and soil texture determination) using hydrometer method of Bouyoucos

i. 52.0 g of air-dried soil samples were weighed into 250 ml beakers.

ii. 20 ml of 20 % Hydrogen peroxide (H_2O_2) were added to the samples in the beakers, and were left to stand until they got wet, after which they were dried on a hot plate and grinded.

iii. 100 ml of 5 % Sodium hexametaphosphate/Calgon $(NaPO_3)_6$ were added and mixed thoroughly, after which they were left to stand for between 15 – 20 hours.

iv. The contents in the beakers were then washed into soil cup with distilled water, and were stirred with dispersing machine for 2 minutes.

v. The cup was disconnected then the contents washed into 1 litre soil cylinders and were filled to the litre mark with distilled water.

vi. The mouths of the cylinders were closed with rubber stoppers and turned completely upside down and back about 20 times.

vii. Few drops of Amyl alcohol $(C_5H_{11}OH)$ were quickly added on top of the suspension to dissipate froths where they appeared.

viii. Hydrometer was gently placed in the soil suspensions and first reading taken within 40 seconds. The hydrometer was removed and washed with distilled water.

ix. After exactly 2 hours of continuous sedimentation, the second reading was taken with the hydrometer. The hydrometer was removed and washed with distilled water.

x. The relative amounts of sand, silt and clay were then calculated using the formula below:

% Sand = 100 – 2 (X+2.88); % Clay = 2 (Y+2.88); % Silt = 100 – (A+B)

Where; X = First corrected hydrometer reading = 1st Hyd. Read – 6.5

Y = Second corrected hydrometer reading = 2nd Hyd. Read – 6.5

A = % Sand; B = % Clay

Once the relative amounts of sand, silt and clay were known, the soils' textural classes were determined by using a soil textural triangle.

Organic carbon

Organic carbon was analyzed by the Walkley and Black wet combustion method.

Determination of Organic Carbon in Soils by Walkley-Black Method and subsequent estimation of Organic matter

i. 1.0 g of air-dried soil samples were weighed into 500 ml conical flasks, and were placed under fume chamber.

ii. 10 ml of Potassium dichromate were added to the samples in the flasks, followed by 20 ml of Concentrated Sulphuric acid (Conc. H_2SO_4).

iii. The flasks were swirled vigorously for one minute and were allowed to stand for 30 minutes.

iv. 200 ml of distilled water were added, followed by 10 ml of Orthophosphoric acid (H_3PO_4).

v. 10 drops of diphenylamine indicator were added to the contents in the flask and were swirled to mix well.

vi. The samples were then titrated with standard Ferrous Ammonium Sulphate until the solutions were purple or blue.

vii. Small lots of the Ferrous Ammonium Sulphate were added to the solutions until the colour flashed to green.

viii. Exactly 0.5 ml of standard Potassium dichromate was added to give an excess and then titrated drop by drop with the Ferrous Ammonium Sulphate until the blue colour just disappeared.

ix. Blank titrations were carried out in an identical way using the same reagents, but omitting the soil.

x. The percentage organic carbon in the soil samples were then calculated using the formula below:

% Organic Carbon = [Dichromate used – (Factor x Titre value of sample)] x Soil factor

Where; Dichromate used = 10.5

Factor = <u>Dichromate used</u>

Mean Blank titre value

Soil factor = 0.39

% Organic Matter (OM) was calculated by multiplying the % Organic Carbon (OC) value by a factor of 1.724 (van Bennelen factor). Thus %OM = %OC X 1.724.

Data Analysis

Data on plant growth, chemical characteristics of plant material and soils were subjected to analysis of variance by using GenStat statistical software package Version 12.1. Data on seedling growth and physiology and chemical properties were analysed using ANOVA. Treatment means were compared using the least significant difference (LSD) method at *p< 05.*

CHAPTER FOUR

RESULTS AND DISSCUSION

This section addressed results and presentation of data and the discussion of findings.

Properties of Soils and Raw Materials of the Treatments

The texture of the soil was loamy sand with 81.24, 16.00, and 2.76 % of sand, silt and clay, respectively. The sand and clay contents of the soil were found to be adequate to hold sufficient soil moisture for cocoa seedling growth (Pagel, 1982). The ratio of sand to clay was wide indicating that, the soil was highly weathered (Pagel). Soil texture influences soil structure, fertility, water and nutrient holding capacity, and also affects certain physico-chemical processes in the soil. The soil texture of loamy sand is ideal for good pore space and therefore good aeration for the soil microbes and fauna. There is also good percolation of water (Pagel). Water holding capacity is low which could be addressed by addition of organic matter and frequent watering will also address this problem (Ahenkorah, 1981).

The pH of the soil was 6.61, indicating slight acidity typical of a WACRI Series or Forest Ochrosols or Ferric Lixisols and may be responsible for the low exchangeable cations (EC) level in the soil (Table 1). The percent organic matter content of 1.50 % was below the critical minimum of 3% found suitable for cocoa cultivation in Ghana (Ahenkorah, 1981). This suggests the need to increase the soil organic matter (SOM) content to give opportunity for optimal growth of cocoa on the soil. Total nitrogen (TN) of 0.17% was higher than the critical minimum of 0.09% required for cocoa cultivation

(Ahenkorah). As regards the available phosphorus (AP) of 19.38 mg kg-1, the value for the soil was found to be lower than the critical value of 20 mg kg-1 considered suitable for cocoa cultivation (Ahenkorah). The soil has exchangeable potassium of 0.175 cmol kg-1 that was even lower than the critical value of 0.25 cmol kg-1 considered ideal for cocoa cultivation (Ahenkorah). The K content was probably due to the lower levels of kaolinitic clay minerals in the soil. Exchangeable Ca and Mg contents of the soil were 4.75 and 2.24 cmol kg-1 respectively which was below the range suitable for the growth of cocoa (Ahenkorah). These low levels of organic carbon (OC), N, Ca and Mg show that the soil used was intensively leached and low in fertility. The soil would benefit positively from OM addition and external source of nutrients hence the need for the testing of external sources of nutrients such as Sidalco liquid and Green OK foliar fertilizer, and Elite and NPS granular fertilizers.

Initial soil parameters show percentages of the various soil nutrients. Organic Carbon content was 1.50 %. Carbon-nitrogen ratio was 8.62 in its initial state. The pH was 6.61. Phosphorus had an initial concentration of 19.38 mg kg^{-1} in the soil. The baseline soil potassium content was 0.175 Cmol kg^{-1}, magnesium was 2.24 Cmol kg^{-1} and calcium was 4.75 Cmol kg^{-1} before treatments were applied.

Table 2: *Soil Chemical Properties*

Chemical Properties	% Carbon	% Nitrogen	Carbon: Nitrogen ratio	pH	Phosphorus (mg kg^{-1})	Potassium (Cmol kg^{-1})	Magnesium (Cmol kg^{-1})	Calcium (Cmol kg^{-1})
	1.50	0.17	8.62	6.61	19.38	0.175	2.24	4.75
Critical levels	3.5	0.09	-	.5.6	20	0.25	1.33	77.5

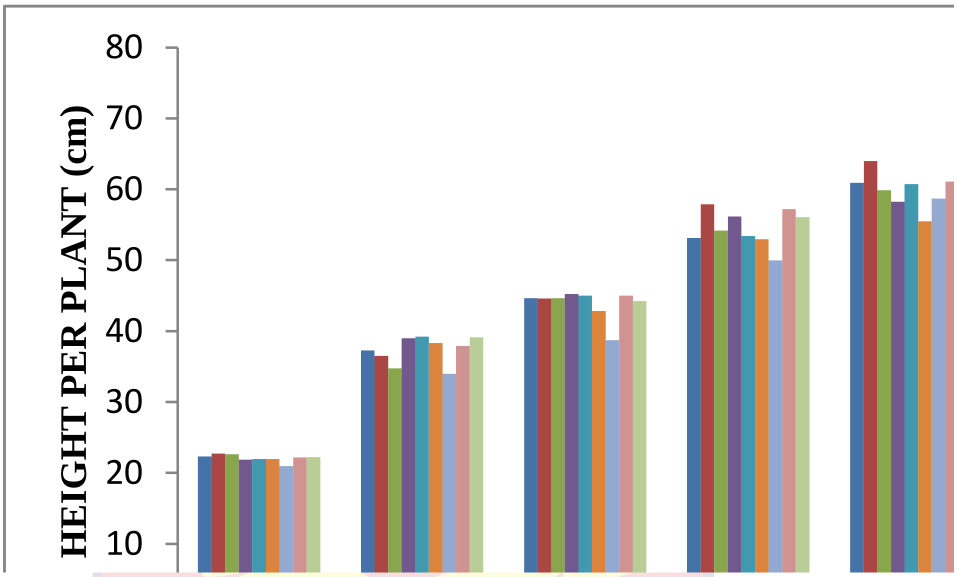
Source: Field data, 2020Effect of Treatment on Growth Parameters

Effect of treatment on plant height

Plant height increased significantly ($p<0.05$) with months from January to June after emergence irrespective of the treatments (Figure 4). Treatment height was lowest in month one after emergence and highest in month 6. Considering the increase in height of the various treatment plants for month 1, T2=Sidalco level 2, recorded the highest followed by T3=N-P-S level 1, with the lowest recorded in T7.

Green OK. In month one seedling height in treatment 2 was found to significantly ($p<0.05$) higher than T7. Considering the plant heights in month 3 treatments 7 was significantly higher from all the treatments with the exception of treatment 6. The highest and lowest heights were recorded in T1 (72.74cm) and T4 (63.0 cm) respectively. Months four, five and six showed no significant difference among the various treatments.

From the results, it could be realized that Sidalco Liquid fertilizer and Elite did well at the last month. Sidalco Liquid fertilizer applied to the plant generally increased the plant height. Soil amended with NPS generally reduced the plant height most often this could be explained by the fact that foliar fertilizers contain in addition to the nutrients elements, plant hormones which influence the physiological activities of the plant. NPS granular fertilizer applied to the soil at the last month showed reduction in plant height. Green OK performed well as the second to last of the various treatments.

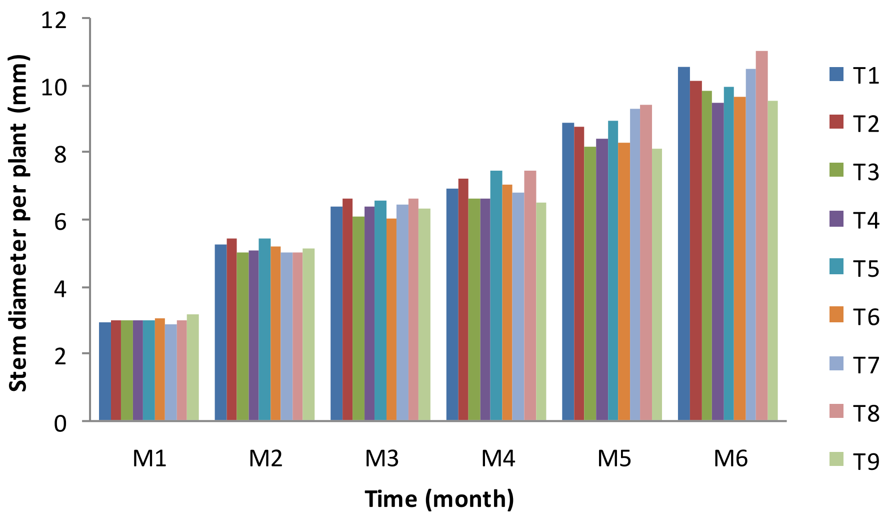


Key: (M1=January, M2=February, M3=March, M4=April, M5=May, M6=June)

Figure 4: Effect of various fertilizer treatments on height of cocoa seedlings.

Effect of treatments on stem diameter

Stem diameter was highest in month 6 for T8 (11.03mm) and the lowest in T4 (9.46 mm) (Figure 5). Considering the treatments, stem diameter was significantly influenced by treatments in month 1 (M1) and month 6 (M6). Plant stem diameter shows significant different in T7 and T9 at ($p < 0.05$) whiles in month 6 T4, T9, T6 and T3 were significantly different from T8. The treatments during month one had significant difference between the treatments 7. Elite had the smallest girth measured. Treatment T1, T4, T3, T2, T8, T5and T6 had the significant difference between them and control T9 had the largest girth measurement in month one. The second month had the least girth and T2 Sidalco had the largest girth. The third month showed no significant difference but treatment T6 Green OK had the smallest girth and T2 had the biggest girth. During the fourth month there was no significant difference between the treatments but the control T9 showed the least girth and T8 Elite had the biggest girth. Measurement taking in month five had no significant different between the treatments. The control T9 had the least girth measured and T8 Elite fertilizer had the biggest girth .The sixth month showed significant different T4 N-21, P-14, K-11 recorded the least, then control T9, T6-Green OK and T3 N-21, P-14, K-11 were the equal and T5, T2, T7 and T1 shown the same statistically values and T8 Elite level 2 had the biggest girth as shown in the graph above.

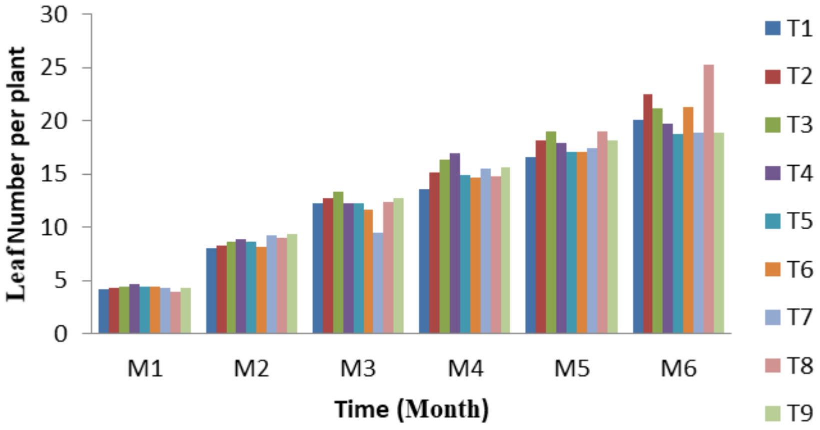


Key: (M1=January, M2=February, M3=March, M4=April, M5=May, M6=June)

Figure 5: Effect of various fertilizer treatments on stem diameter of cocoa seedlings.

Effect of treatments on leaf number

Treatments effects on Leaf Numbers of cocoa seedlings during the various months are presented in Figure 6. Significant difference was found only in month 3. Months 1, 2, 4 and 5 showed no significant differences among treatments. At the end of the sixth month treatment 2 and 8 showed more leaf number indicating Sidalco foliar double rate and Elite granular fertilizer double rate performed well among the various treatments. Treatment 3 and 4 NPS and treatment 5 and 6 Green OK did not perform very well in terms of leave numbers.



Key: (M1=January, M2=February, M3=March, M4=April, M5=May, M6=June)

Figure 6: Leaf Numbers of cocoa seedlings as affected by fertilizer treatments.

Effect of treatments on root volume

There were significant increases ($p<0.05$) in root volume with time (Figure 7). The root volume increased from month 1 to month 6 in all the treatments. Root volume readings in month 1 shows that treatment T7 had the lowest root volume whiles T 2 had the highest root volume. In month 2, T3 had the lowest volume whiles T7 had the highest. Considering the root volumes from month 3, treatment 8 recorded the highest of (4.4 cm^3) whiles treatment 1 recorded the lowest of (3.0cm^3). In month 4, root volume of treatment 7 was significantly ($p< 0.05$) higher than treatment 1. In month 5, T7 had the highest whiles T3 had the lowest. In month 6, T7 finally recorded the highest of 13.22cm^3 whiles T4 recorded the lowest root volume of 8.89

cm^3. Treatment 7 which is the highest level of Elite incorporated in the soil relatively improved on the root volume followed by higher level 2 of Sidalco NPK 10: 10: 10. Treatment level 7 and 2 showed the highest root volume.

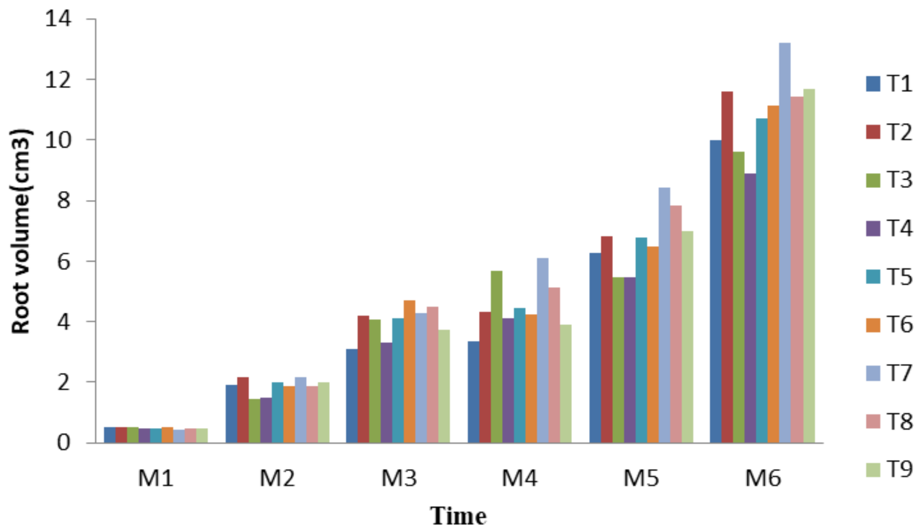
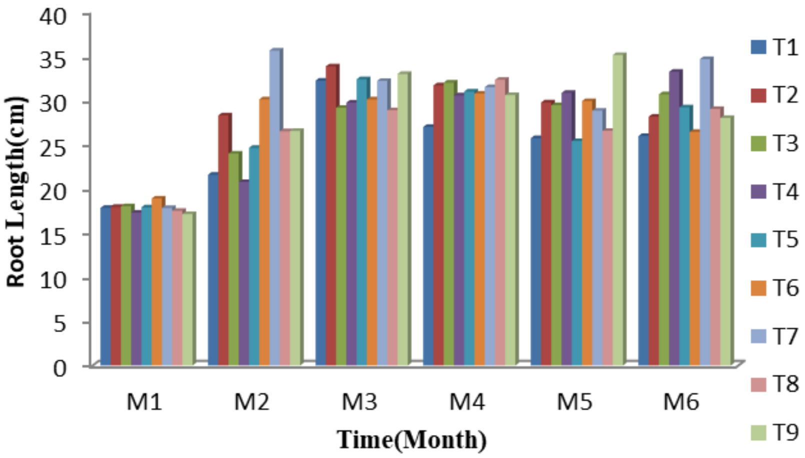


Figure 7: Root volume of cocoa seedlings as affected by fertilizer treatments.

Effect of treatments on root length

Treatments effects on root length of cocoa seedlings for the various months are presented in Figure 8. There were no significant differences among the treatments in month 1. Measurement taken in month 2 shows T7 having the highest root length whiles T 4 had the shortest root length. In Month 3, T2 had highest root length whiles T8 had the shortest. Readings for month 4 had T3 and T1 as having the longest and shortest root lengths, respectively. The control T 9 recorded the longest in month 5 whiles T5 had the shortest roots.

Finally, the root length readings of month 6 were 34.64 cm for T7 and 25.94 cm for T1 as the longest and shortest respectively. This indicates that, the organic fertilizer addition did satisfy the nutritional demands of the seedlings, and therefore, supported their optimal growth. This difference was significant at (p < 0. 05).



Key: (M1=January, M2=February, M3=March, M4=April, M5=May, M6=June)

Figure 8: Root length of cocoa seedlings as affected by fertilizer treatments.

Effects of Treatments on Fresh and Dry Vegetative Parts of Plants

Effect of treatments on fresh leaf weight

Treatments effect on fresh leaf weight of cocoa seedlings for the various months as shown in Figure 9. There was significant difference ($p<0.05$) among the leaf fresh weight of the treatments along the months. In month 1, T9 and T5 had 1.762 g and 1.418 g being the highest leaf and lowest weights respectively. The leaf fresh weights of the remaining treatments in that month showed no significant difference ($p > 0.05$).

During the second month, T 7 had the least and T9 had the highest. There were no significant differences among the treatments. In month 3, T9 (control) showed the lowest and T4 had the highest. Treatments 9, 1 and 5 were statistically the same and treatments 2,6,7,8 and 3 had the same weights. In months 4, T7 had the lowest root length and T8 had the highest leaf fresh weight. Readings from month 4 had no statistical differences among the treatments. Month 5 had T6 and T7 recording the lowest and highest leaf fresh weight respectively. During month 6, T9 recorded the least (12.44g) and T8 had the highest (19.50g). In the overall performance, T 8 (Elite level 2 fertilizer) performed better than the rest of the treatments. Organic fertilizers are known to improve the physical properties of the soils, help the soil to maintain better tilth, and increase water holding capacity. With the high fresh leaf weight, one would expect increased photosynthetic rate in order to increase dry matter production as stated by Oyewole (2012) and Olanipekun (2012). Organic fertilizers are known to improve the physical properties of the soils and help the soil to maintain its nutrient value.

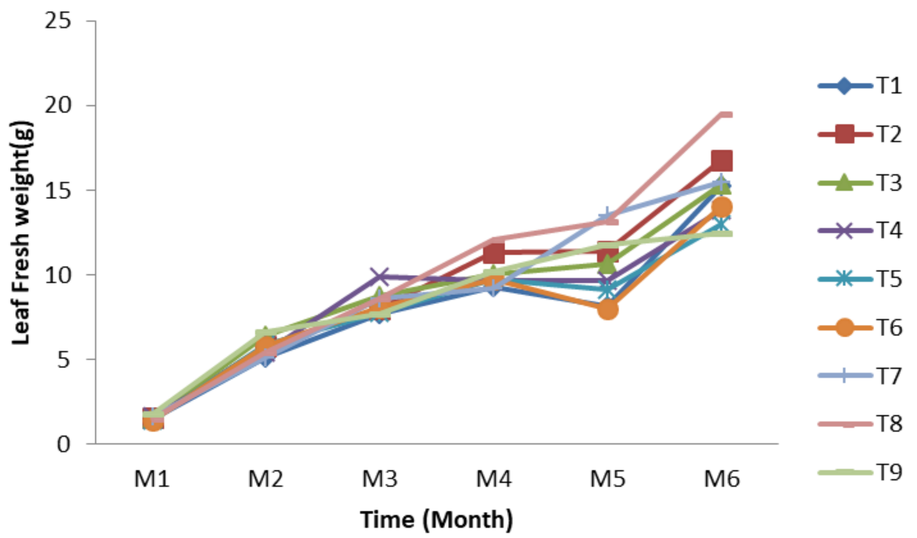


Figure 9: Leaf fresh weight of cocoa seedlings as affected by fertilizer treatments.

Effect of treatments on stem fresh weight

Stem fresh weight of cocoa seedlings during the various months of treatment applications are shown in Figure 10. There was significant differences ($p<0.05$) among the treatments along the months. For month 1, there were no significant differences among treatments. Month 2 recorded T3 as the lowest and T9 the highest. Treatments7 had the second least weight. Treatments 4,8,5,6 and 2 showed no significant differences in stem fresh weights. Month 3 showed no significant difference among the treatments. Month 4 also showed no significant difference among the treatments though T5 showed the least weight and T8 showed the heaviest weight. Month 5 showed T4 having the least fresh stem weight and T8 the highest stem fresh weight. Treatments 6, 5,9,3,2 and 7 are statically the same. Treatment 7 had the least weight while treatment 8 had the highest weight in month 6. Treatment 8 did perform in stem fresh weight as stated by Oyewole (2012).

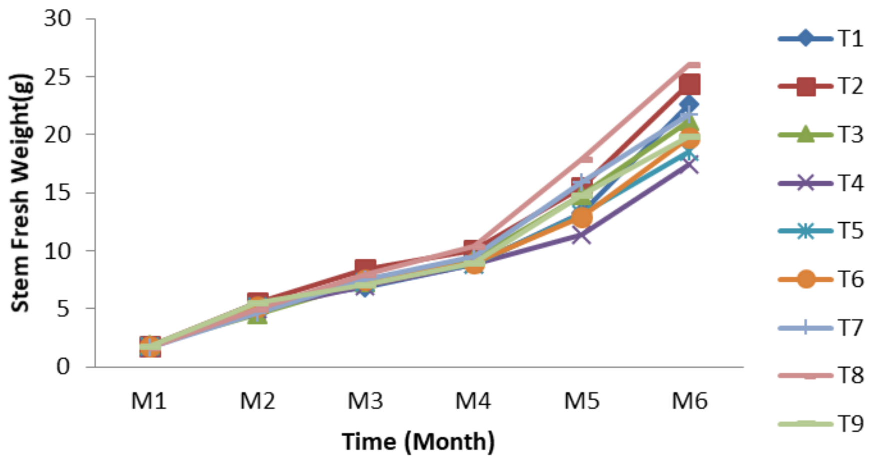


Figure 10: Stem fresh weight of cocoa seedlings as affected by fertilizer treatments.

Effect of treatments on root fresh weight

Root fresh weight of cocoa seedlings during the various months of treatment applications as presented in Figure 11. There were differences in the fresh root weights of the treatments with time. Month 1 showed no significant differences among the treatments. Root fresh weights in the remaining months from months 4 to 6 showed significant differences ($p<0.05$). Treatment 9 control had the highest fresh root weight followed by treatment 8 Elite double rate.

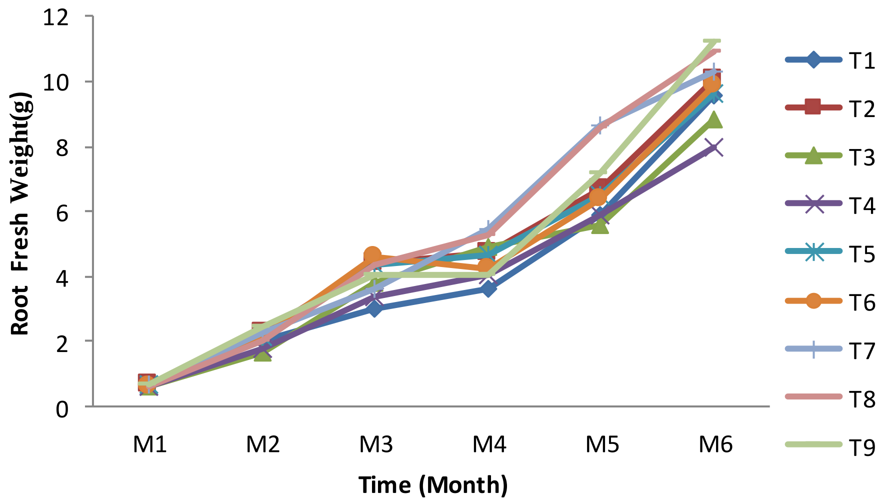


Figure 11: Root fresh weight of cocoa seedlings as affected by fertilizer treatments.

Effect of treatments on leaf dry weight

Leaf dry weights of cocoa seedlings during the various months of treatment application are presented in Figure 12. There were significant differences ($p<0.05$) among leaf dry weights of the treatments with time in months. In month 1, T1 had the lowest dry leaf weight and T9 had the highest dry leaf weight with 0.4578g and 0.5544g respectively. In Month 2, T1 and T9 had the lowest and highest leaf dry weights of 1.376g and 1.732g respectively. Month 3 had T 1 (2.206 g) as the least and T3 had (2.656 g) as the dry weight. In month 4, still T1 recorded the least weight of (2.497 g) and T8 recorded the highest dry weight (3.367 g). Month 5 had treatment 1 recorded the least at 3.022g and treatment 9 had the highest weight of (6.722g). Treatments 5 and 6 also had the least weight and treatments 4, 3, 2, 8 and 7 had the same statically equal. Month 6 show no significant differences among the treatments. Treatment 8 Elite fertilizer level 2 did well as stated by Oyewole (2012).

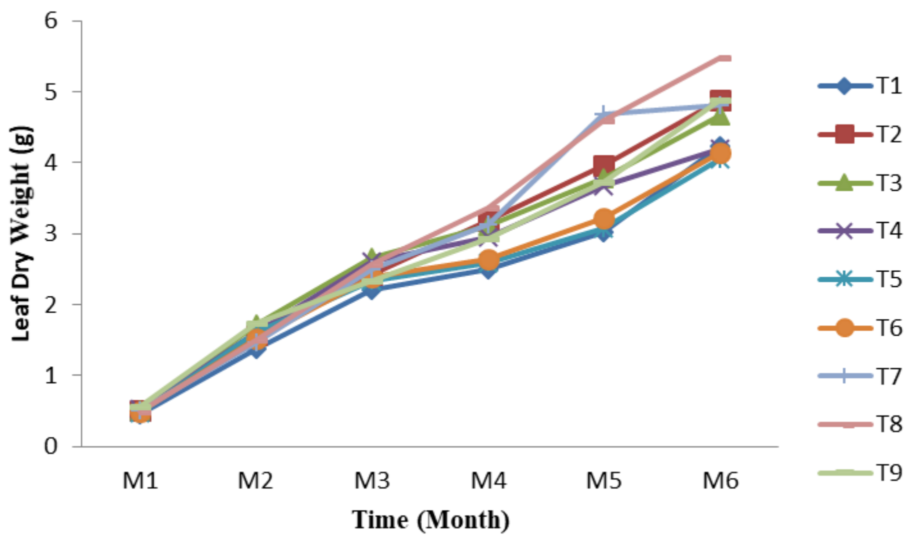


Figure 12: Leaf dry weight of cocoa seedlings as affected by fertilizer treatments.

Effect of treatments on stem dry weight

Stem dry weight of cocoa seedlings during the various months after treatment application are presented in Figure 13. During month 1, no significant difference was observed among the treatments. In month 2, T3 recorded the least of 0.927g whiles treatment 9 recorded the highest weight of 1.176g. The remaining treatments were statically equal. Reading from month 3 shows treatment 4 the smallest weight recording 1.419g and treatment 2 had1.914. The other treatments had the same weight but differ in number but statically equal. The weighing from month 4 showed no significant difference between the treatments. Treatment1 recorded the least of 1.611g and treatment 8 had the highest stem dry weight of 2.111g. There was no significant difference among the treatments. Data taking during month 5 treatment 4 had the least of 3.222 g and treatment 8 had the highest stem dry weight of 4.4679 g. There was no significant difference among the treatments. Month 6 showed no significant difference among the treatments. Treatment 4 had the least weight of 4.084 g and the treatment 8 had the highest of 5.286. Treatment 8 is showed very well in the stem dry weight.

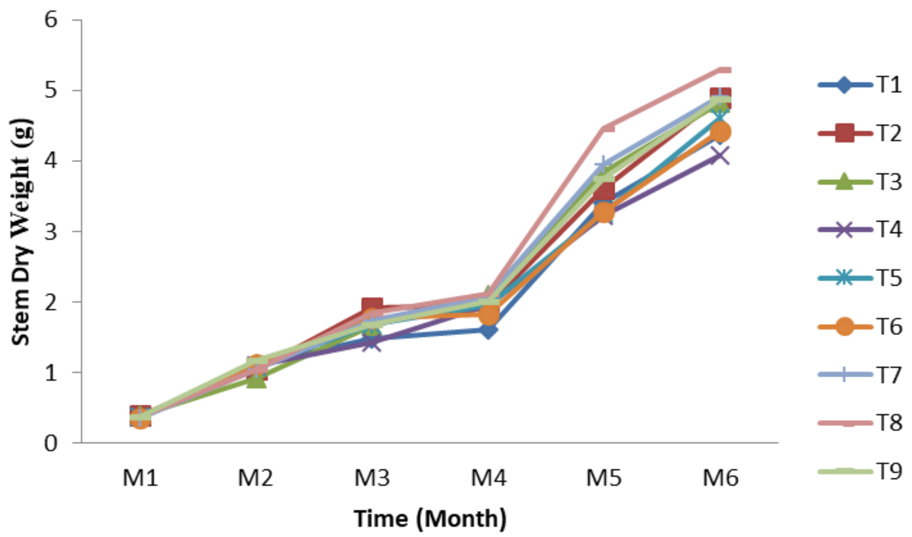


Figure 13: The effect of fertilizer treatments on stem dry weight.

Effect of treatments on root dry weight

Root dry weights of cocoa seedlings during the various months are presented in Figure 14. Month 1 had treatment 9 as the least of the root dry weight of 0.1922 g and treatment 3 had the highest of root dry weight of 0.2778 g. Month 2 showed treatment 3 as the least and treatments 4, 8,1,6,2 and 5 showed the same statically equal. Treatment 9 and 7 were the highest 0.5544g. Month 3 showed no significant difference between the treatments recoding treatment 4 as the least of 0.6644 g and treatment 6 as the highest of 1.0611(g). Month 4 showed treatment 1 as the least weight of 0.783g and treatment 7 as the highest of 1.257 g. Month 5 had T1 the least treatment of 1.444 g for treatment and the highest T9 of 2.067 g and the last month had treatment 4 as the least of 1.956 g and the highest was treatment 9 of 2.788 g. Treatment 8 Elite fertilizer level two did well among the treatment.

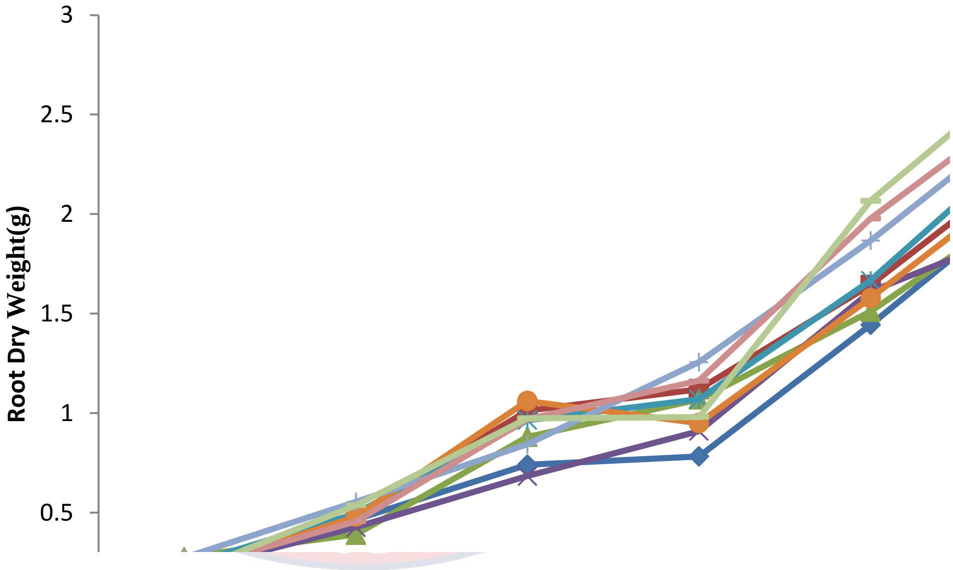


Figure 14: Effect of fertilizer treatments on root dry weight (g).

Nutrient Uptake by Plants

Effect of treatments on plant nitrogen content

Nitrogen contents of cocoa seedlings during the last months are presented in Figure 15. Nitrogen content was significantly influenced by various treatments (<0.05). The T9 showed the lowest in the nitrogen 1.67% and T3 had the highest nitrogen content of 2.384%. Nitrogen content in treatments 8, 4, and 1 were 2.078%, 2.137% and 2.265% respectively. The NPS granular fertilizer treatment 3 with high nitrogen concentration increased the leaf dry weights of the seedlings. This is in line with the findings of Lockwood and Asomaning (1963), who also found increase leaf dry matter yield with the application of fertilizer with high nitrogen source. The Nitrogen nutrient uptake was higher in the inorganic fertilizers as compared to the organic fertilizers both foliar and granular ranging from 31%,36%,43% and 28% for treatments 1,2,3,4 and 20%,14%,18% and 24% for treatments 5,6,7, and 8.

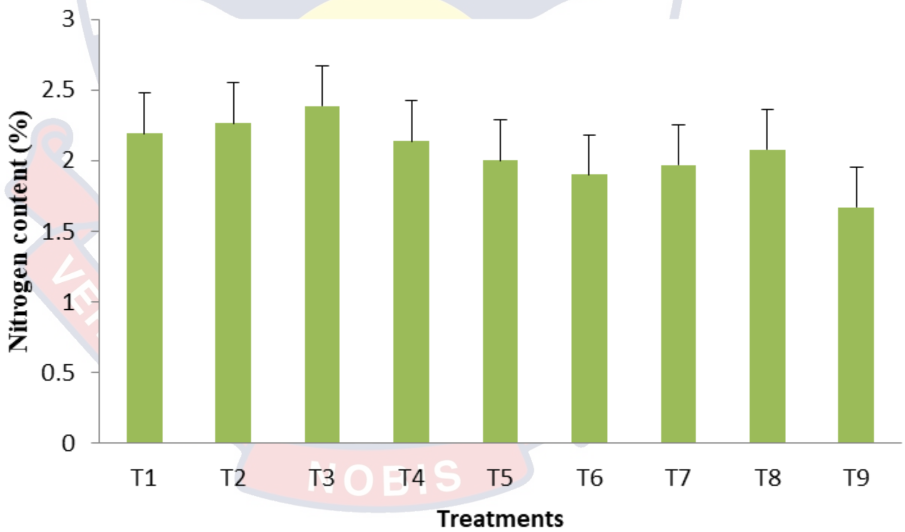


Figure 15: Nitrogen content as affected by the fertilizer treatments in leaves of cocoa seedlings.

Effect of treatments on phosphorus content of leaves

Phosphorus content in leaves of cocoa seedlings was significantly ($p<0.05$) influenced by various treatments at 6 months after sowing (Figure

16). Phosphorus content in leaves shows treatment 9 had least of 0.3217% and treatment 4 had the highest of 0.4901%. Treatment 5 had 0.3796% while treatment 8 had 0.3804%. Treatment 6, 7, 1 had 0.3856%, 0.4019% and 0, 4053 % respectively. Treatment 2 had 0.4129% and treatment 3 had 0.4698%. Treatments 3 and 4 granular inorganic fertilizer NPS performed well on the phosphorus content on the plant nutrient uptake in the leaves at the last month of the trial. The results of this study also corroborated the report that leaf P concentration of citrus increased with integrated use of organic and inorganic fertilizers. C. Singh and B. B. Sharma, 1993.The percentages at the last month was all positive ranging from 18% to 52% both the inorganic show highest in foliar and granular as compared to the organic both foliar and granular. Potassium concentrations in leaves were below the normal concentration reported for cacao trees D. B. Murray 1967 and F. N. Fahmy.

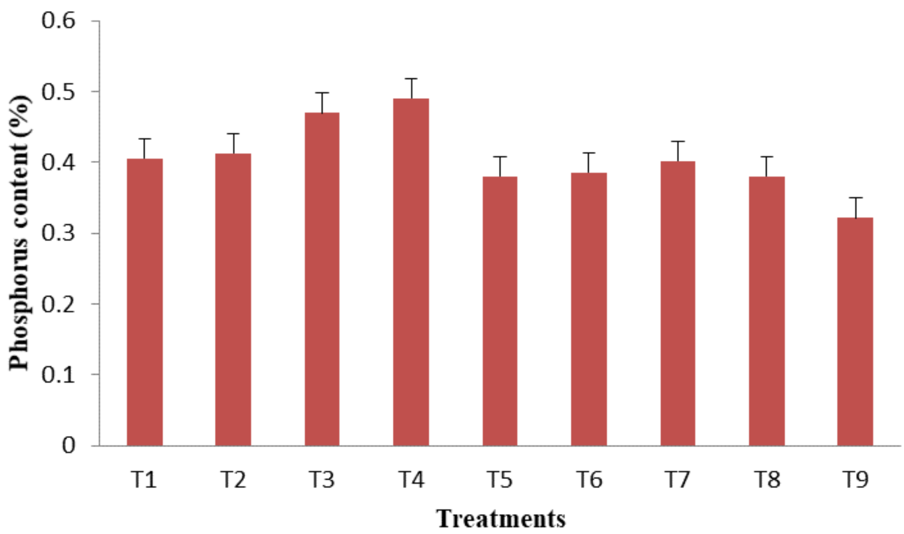


Figure 16: Phosphorus content as affected by fertilizer treatments**.**

Effect of treatments on potassium content of leaves

Potassium content in leaves of cocoa seedlings was significantly ($p<0.05$) influenced by various treatments 6 months after sowing (Figure 17). Potassium recorded for treatment 9 was 0.771% as the least and treatment 8 had the higher of 1.691%. Treatment 5 had 1.037% Potassium whiles treatment 6 had 1.125%. Treatment 4 had 1.152%. Treatment 3 had 1.264%. Treatment 7 had 1.429% while treatment 2 and 3 had 1.547% and 1.557% respectively. Treatment 8 Elite granular fertilizer did well among the various treatments. Treatment 2 and 3 also did well as foliar fertilizer uptake of nutrients is much faster than root uptake. Therefore, foliar feeding is the method of choice when deficiency symptoms are noted, and prompt correction of deficiencies is required. Nutrients rapidly absorbed through the foliage, providing the plant with the missing nutrients, and strengthening it.

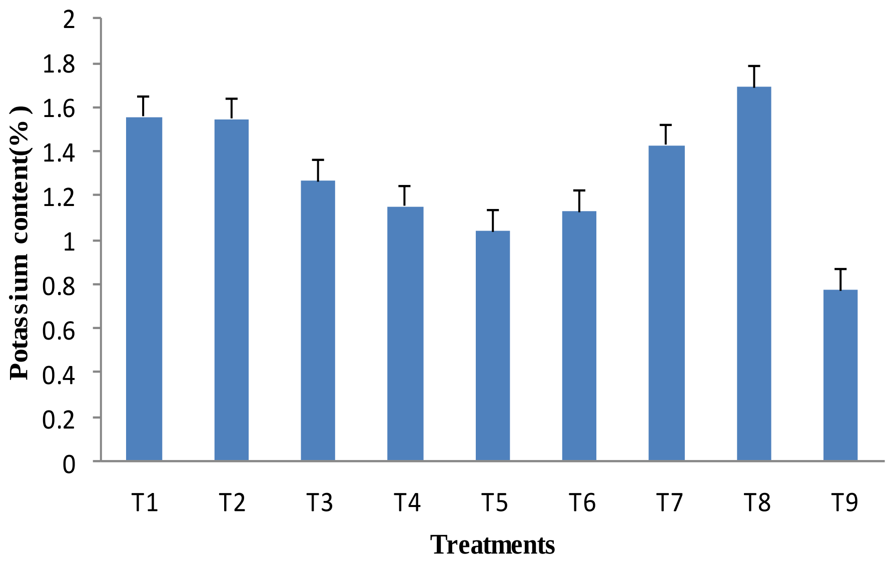


Figure 17: Potassium content of cocoa seedlings as affected by fertilizer treatments.

Effect of treatments on leaf magnesium content

Magnesium contents in leaves of cocoa seedlings was significantly ($p<0.05$) influenced by various treatments 6 months after sowing (Figure 18). Treatment 8 had the least of 0.4797% of Magnesium whiles treatment 5 had the higher magnesium content of 0.7066%. Whiles treatments 4, 2, 3 had the same amount of magnesium. Treatments 1 and 6 are the same whiles treatments 7, 9 and 5 had the highest magnesium content. Treatment 5 which is an organic foliar fertilizer level one had the highest amount of magnesium content. The percentage calculated for the various treatments shows negative in all treatment expect for treatment 6 which had 4% for the plant nutrient content organic foliar all the others had 12% and -20 for treatment 1 and 2 which is inorganic foliar, treatments 3 and 4 had -20 and 21% for the inorganic granular, the organic foliar had the least of 4% and -6% and treatment 7 and 8 which was the organic granular had -2% and -29%.

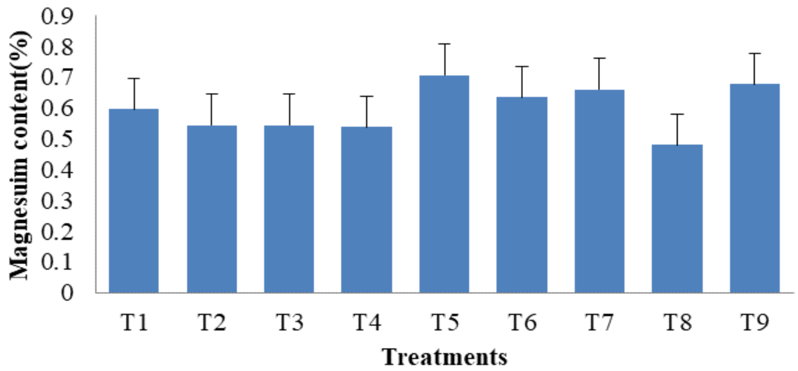


Figure 18: Magnesium content in cocoa leaves as affected by fertilizer treatments.

Effect of treatments on leaf calcium content

Calcium contents in leaves of cocoa seedlings was significantly ($p<0.05$) influenced by various treatments 6 months after sowing (Figure 19). Treatments 1,8,3 had the least of 1.112% calcium content in the leaves respectively, whiles and 7 had 1.186%, whiles treatment 9 had 1.229%. Treatments 4 and 5 had 1.325 and 1.347%. Treatment 6 had 1.379 % and treatment 3 had the higher of 1.454% in calcium content. Treatment 3 that is NPS had the highest percentage of calcium which is a granular fertilizer content. The percentage Calcium calculated at the last month had significant differences among the treatments 1 and 2 the inorganic foliar had -10% and -9% and the inorganic granular had 18% and 10 %.The organic foliar had 8% and 12% for treatments 5 and 6 and the granular had -3% and 10% for treatments 7 and 8.

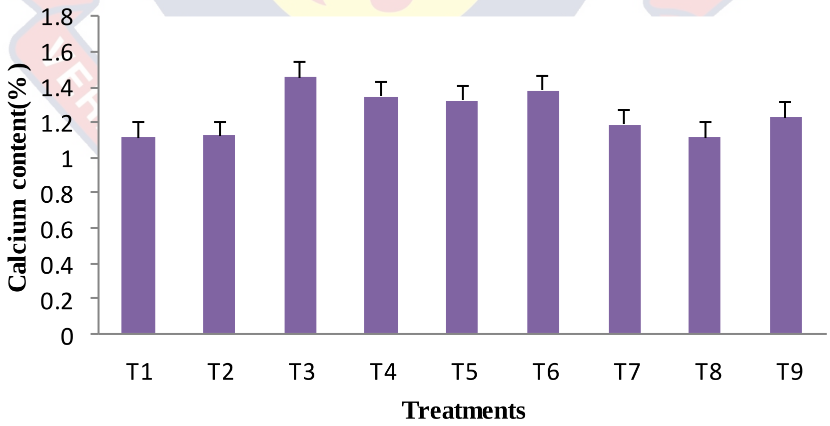


Figure 19: Leaf calcium content of cocoa seedlings as affected by fertilizer treatments.

Soil Data Analysis for the Various Treatments

Significant differences ($p<0.05$) was observed in pH of soils of various treatments (Figure 20). The initial pH was 6.61. During the experimental period pH fluctuated between 4.79 and 6.69 for treatment in month 6 and 2 respectively. Treatment 4 month 5 dropped considerably compared with the initial soil pH with the exception of treatment 9 month 3.T6 and T8 of month 4, T6 and T9 of month 2. The initial pH was highest than the rest of the treated soil.

Although under ideal conditions, soil pH of T1 Sidalco, Green OK and control had no soil amendments and therefore the treatments should have behavioural and maintain the pH of the initial soil. Slight changes occurred as the soil underwent some level of incubation within the experimental period of six months. Soil pH was significantly ($p<0.05$) influenced by different treatments during the trial period. In month 1, T4 was significantly less than T3 and T5, T1, T6, T8 and T9 whiles T2 less than T7 were significantly different ($p<0.05$). In month 2 treatment were significantly different at ($p<0.05$). The T5, T9 and T8 were significantly higher than T4, T3, T1, T8, T2 and T7. Soil pH of T4 was the lowest whiles T3 less than T8 less than T3 less than T1 less than T8, less than T2 less than T7.

In month 3 the soil pH was significantly ($p<0.05$) influenced by treatments with T9 recording the highest pH of 6.68 while T4 had the lowest of 4.49. Soil pH was in order of T3 < T1 < T2 < T5 =T8 =T7 < T3. In month 4 T6 recorded the highest of 6.67 whiles T3 recorded the lowest. T4 less than T9 less than T2 less thanT1 less thanT7, T5, less than T8. In month five T9 having the highest soil pH of 6.29 whiles T4 had the lowest of 4.79. These two treatments were significantly different at (p<0.05) changes in soil pH for the treatments were not significantly among month (p>0.05). Soil pH observation was made by Ofori-Frimpong *et al*. (2010) who found a depressive effect of cocoa seedling growth following the application of inorganic NPK fertilizer NPS was used which contain all the necessary nutrients needed for cocoa seedling growth. CSIR NPS level 1 and level 2 for treatment 3 and 4 had the lowest pH in most of the months as a result of high NPS applied to the soil rendering the soil slightly acidic. The pH was highest in the inorganic fertilizers but low in the foliar fertilizers as compared to the granular which ranges from -7% to -10% for treatments 1and 2 and -12% and-24% for treatments 3 and 4. The organic fertilizers both foliar and granular show low pH for the foliar it was -6 %and -3% for treatments 5 and 6 and -2% for treatments 7 and8 respectively.

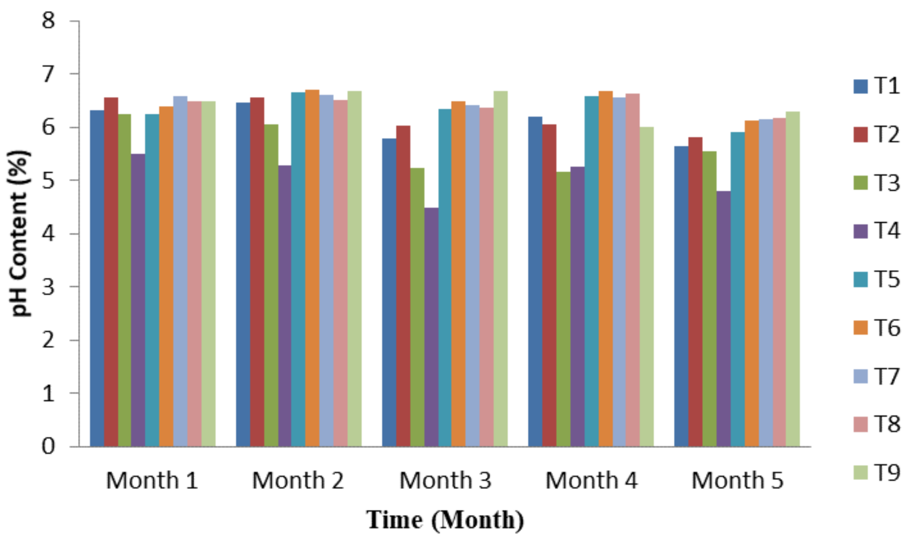


Figure 20: pH of soils as affected by fertilizer treatments.

Effect of treatments on soil nitrogen contents

The initial total nitrogen content of the soil was 0.17%. There were no significant differences ($p>0.05$) among the treatment for the month 1. In month 1, treatment 2 had the least nitrogen content of 0.08% while treatment 9 had the highest of 0.10%. There was no significant difference among the treatment in month 1 but there was reduction in the nitrogen content in the soil after treatments were applied. During the month 2, treatment 7 (0.07%) and 9 (0.11%) had the lowest and highest soil nitrogen content of the soils respectively (Figure 21). Although the nitrogen contents where still lower than the initial nitrogen content of the soil, nitrogen content of month 2 were higher than those of month 1. In months 3, 4 and 5 there were no significant difference among the treatments nitrogen content in the soil for all these treatments were lower than the initial soil nitrogen of 0.17%. These show that mineralization of organic nitrogen to mineral nitrogen (NH_4^+-N and NO_3^--N) took place during the trial. There is limited research information on how different fertilizers especially foliar fertilizers can effectively be utilized to boost the growth of cocoa seedlings in nutrients poor soils in Ghana (Oppong *et al.*, 2008) Percentages calculations for the various treatments at the month showed low nitrogen content in T3 &T4. The organic fertilizers showed higher negative percentages in then the foliar as compares to the granular fertilizers. Those are the various percentages for the last month data taken from treatment 1 to 8 as we compared then to the control are as follows T1-14, T2 -16, T3-1, T4-1, T5-21, T6-22, T7-21 and T8 -9.

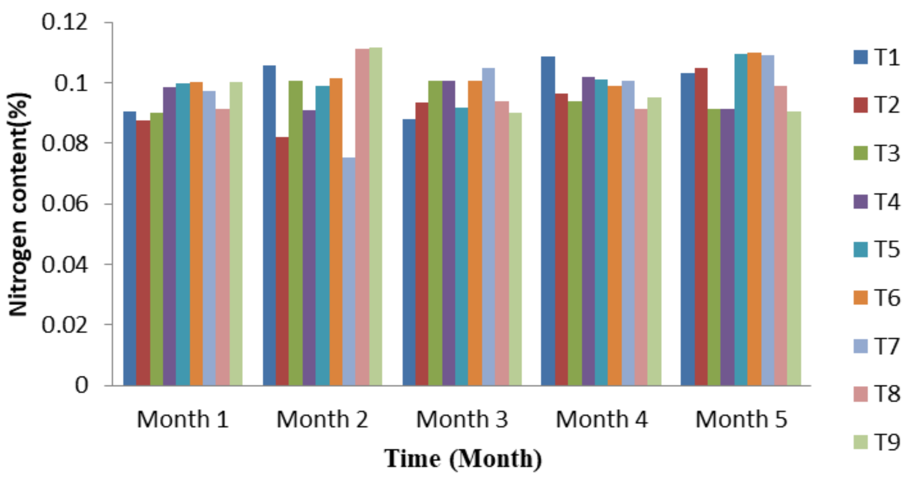


Figure 21: Total Nitrogen content in the soil as affected by fertilizer treatments.

Effect of treatments on soil available phosphorus

Soil available phosphorus content was significantly ($p<0.05$) influenced by treatments (Figure 22). The initial Phosphorus content in the soil was 19.38 mg kg^{-1}. There was significant difference in soil available phosphorus among the treatments. In month 1 treatment 9 had the least of 9.20 mg kg^{-1} whiles treatment 6 had 10.37 mg kg^{-1}. Treatment 5 had 11.22 mg kg^{-1}, treatment 1 had 11.90 mg kg^{-1}, and treatment 7 had 12.24 mg $kg^{-1}$and treatment 2 had 14.79 mg kg^{-1}all these treatments showed reduction in the phosphorus content as compared to the initial content. Treatment 8 had 22.95 mg kg^{-1}, treatment 3 had 29.07mg kg^{-1} whiles treatment 4 had the highest of 57.63 mg kg^{-1} all three treatments had increased in Phosphorus content then the initial content.

In month 2 treatment 6 had the least content of 10.03, mg kg^{-1} treatment 9 had 10.09 mg kg^{-1} treatment 7 recorded 11.22 mg kg^{-1}, and treatment 5 recorded 13.60 mg kg^{-1} treatment 1 and 2 had 14.79 respectively. Treatment 6 16.9 mg kg^{-1}, Treatments 3 and 4 recorded the highest of 41.99

mg kg^{-1} and 89.08 mg kg^{-1} more than the initial content due the fertilizer applied. In month 3, treatment 9 recorded 13.8 mg kg^{-1} as the least whiles treatments had 5 and 6 had the highest of 14.11 mg kg^{-1}. Treatment 7 recorded 14.85 mg kg^{-1}, treatment 1 had 21.75 mg kg^{-1}, treatment 8 had 23.0 mg kg^{-1} and treatment 2 had 23.80 mg kg^{-1}, treatment 3 recorded 52.2 mg kg^{-1} whiles treatment 4 recorded 108.11 mg kg^{-1}.

During month 4 treatment 6 had 15.47 mg kg^{-1} as the least, treatment 9 had 16.7 mg kg^{-1}, and treatment 5 had 18.36 mg kg^{-1}, while treatment 7 had recorded 20.40 mg kg^{-1}. Treatment 8 had 25.84 mg kg^{-1} and treatment 1 had 31.45 mg kg^{-1}, then treatment 2 39.61 mg kg^{-1} whiles treatment 3 73.27 mg kg^{-1} and treatment 101.48 mg kg^{-1}.

During month 5 all treatments had phosphorus content that higher than the initial phosphorus content of 19.38 mg kg^{-1}. Treatment 5 had 22.78 mg kg^{-1} as the lowest, while's treatment 9 had 23.80 mg kg^{-1}. Treatment 6 had 25.16 mg kg^{-1}g/g and treatment 7 had 27.88 mg kg^{-1}, whiles treatment 1 had 42.20 mg kg^{-1} and treatment 2 had 46.92 mg kg^{-1}. Treatment 3 and 4 had the highest of 81.09 mg kg^{-1} and 100.54 mg kg^{-1}. Elite is an organic fertilizer which was added to the soil. NPS was higher due to the phosphorus content then all the other treatments. Sidalco is a foliar fertilizer is a gradually made to the leaves.

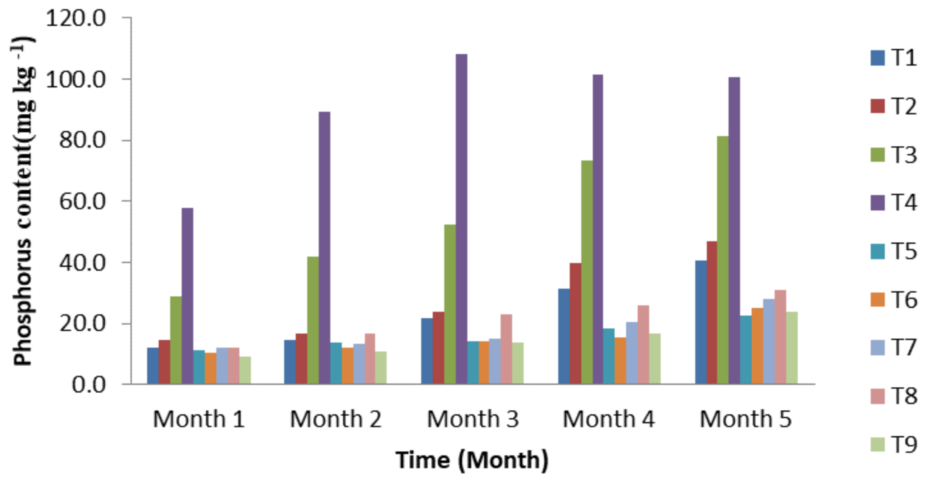


Figure 22: Phosphorus content in the soil as affected by the various treatments.

Exchangeable Potassium content in the soil showed significantly differences ($p<0.05$) among the treatments (Figure 23). The initial exchangeable Potassium content was 0.175 cmol kg^{-1}. During month 1 treatment 5 recorded 0.05 cmol kg^{-1} and treatment 9 also had 0.05 cmol kg^{-1} as the least, whiles treatments 4,6 and 3 recorded 0.07 cmol kg^{-1} respectively, treatments 1 recorded 0.08 cmol kg^{-1} and treatment 7 had 0.09 cmol kg^{-1} and treatments 2 and 8 had 0.11 cmol kg^{-1} as the highest.

During month 2 treatments 9 shows the least of 0.05 cmol kg^{-1}, whiles treatment 5 recorded 0.05 cmol $kg^{-1}$and treatments 4 recorded 0.06 cmol kg^{-1}. Treatments 6 and 3 had 0.07 meq/100g treatments 1 and 7 had and 0.08 meq/100g respectively. Treatments 2 and 8 the highest was 0.10 and 0.11 cmol kg^{-1}.

During month 3 treatments 5 and 9 shows the least of 0.05 meq/100g, whiles treatments 4 ,6 and 3 recorded 0.07 cmol kg^{-1} and treatment 1 recorded 0.08 cmolc kg^{-1}. Treatments 7 had 0.09 cmol kg^{-1}. Treatments 2 had 0.10 and the highest was treatments 8 recording 0.11 cmol kg^{-1}.

During month 4 treatments 5 and 9 shows the least of 0.05 cmol kg^{-1}, whiles treatment 4 recorded 0.06 cmol $kg^{-1}$and treatments 6 and 3 recorded 0.07 cmol kg^{-1}. Treatment 1 had 0.08 cmol kg^{-1}, whiles treatments 7 and 2 had and 0.10 cmol kg^{-1} respectively. Treatments 8 had the highest of 0.11 cmol kg^{-1}.

During month 5 treatments 9 and 5 shows the least of 0.05 cmol kg^{-1}, whiles treatment 4 recorded 0.06 cmol $kg^{-1}$and treatment 6 recorded 0.07 cmol kg^{-1}. Treatments 1 and 3 had 0.08 cmol kg^{-1}, whiles treatment 7 had and 0.0.9 cmol kg^{-1}. Treatment 2 0.10 and the highest treatment 8 had 0.11 cmol kg^{-1}. After treatment application there was a reduction in the amount of potassium rate.

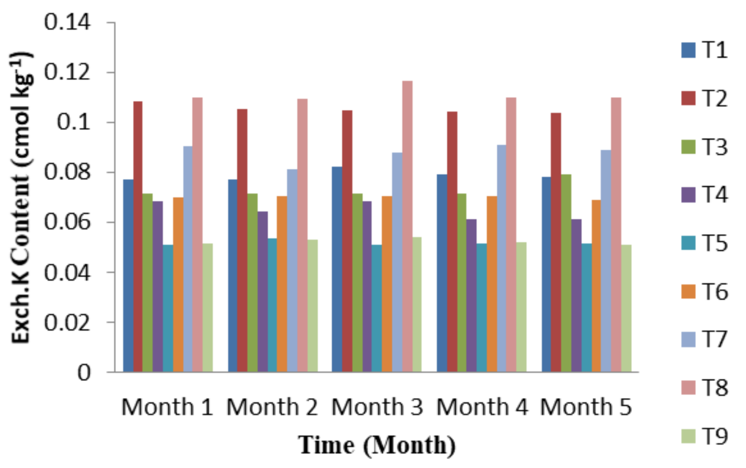


Figure 23: Exchangeable Potassium content in the soil as affected by the treatments

Effect of treatments on soil organic carbon

Soil organic carbon content was significantly ($p<0.05$) affected by various treatments in all the months (Figure 24). The initial organic carbon content in the soil was 1.60%. In month 1 treatment 7 had the least of organic carbon content 0.93%, whiles both treatments 4 and 6 had 0.95% respectively. Treatment 2 had 0.97% and treatment 3 recorded 0.97%. Treatment 3 had 0.99 % whiles treatments 1 and 5 had 1.03%. Treatments 8 had 1.12% and the highest was treatment 8 which had 1.18%, all treatments had reduction in rate as compared to the initial carbon rate of 1.60%.

In month 2 treatment 2 had 0.97% as the least, whiles treatment 8 had 0.99%. Treatment 6 had 1.01% and treatment 4 had 1.03% .Treatment 1 had 1.12% while treatments 3 had 1.14% and had 7 1.14%. Treatments 9 had 1.16 % and the highest was treatment 5 which had 1.20%, all treatments had reduction in rate as compared to the initial carbon rate of 1.60%.

In month 3 treatments 9 had 0.89% as the least, whiles treatments 4 and 2 had 0.93% and 0.97% respectively. Treatment 6 had 1.01% and treatment 7 had 1.01%. Treatment 1 had 1.11% while's treatments 8 and 3 had 1.14%. Treatments 5 had 1.16% as the highest, all treatments had reduction in rate as compared to the initial carbon rate of 1.60%.

In month 4 treatment 4 had 1.09% as the least, whiles treatments 6 had 1.12% and treatment 9 had 1.14% respectively. Treatments 1, 3 and 7 had 1.20% and treatment 5 had 1.24%. Treatment 2 had 1.26% while's treatments 8 had 1.26% as the highest, all treatments had reduction in rate as compared to the initial carbon rate of 1.60%.

In month 5 treatment 3 had 1.14% as the least, whiles treatments 7 had 1.14% and treatments 2 and 4 had 1.16% respectively. Treatments 1 had 1.17% and treatment 8 had 1.18%. Treatment 9 had 1.20% whiles treatments 5 had 1.22%. Treatment 6 had the higher of 1.24%. All treatments had reduction in rate as compared to the initial carbon rate of 1.60. The percentages of

Carbon calculated at the last month shows negatives in the treatments from foliar to granular fertilizers ranging from -2% to 5% which runs through all treatments.

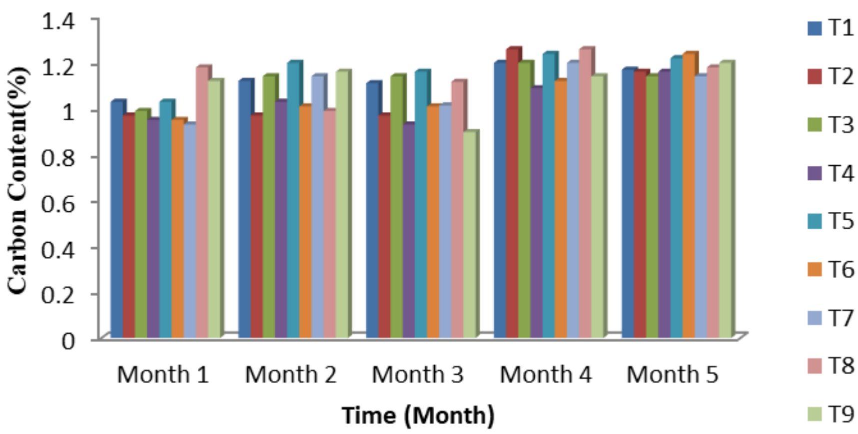


Figure 24: Organic carbon content in the soil as affected by the treatments.

Effect of treatments on soil exchangeable calcium

Figure 25 shows soil exchangeable calcium as affected by various treatments. Exchangeable calcium content in the soils was significantly ($p<0.05$) affected by the treatments with initial soil content of 4.75 cmol kg^{-1}. In month 1 treatment 8 had 3.90 cmol kg^{-1} as the least; whiles treatments 5 and 1 had 4.09 cmol kg^{-1} and 4.12 cmol kg^{-1} respectively. Treatment 6 had 4.16 cmol kg^{-1} and treatment 4 had 4.17 cmol kg^{-1}. Treatment 4 had 4.45 whiles treatments 2 and 7 had 4.37 cmol kg^{-1} and 4.38 cmol kg^{-1} respectively. 1.12 cmol kg^{-1}, and the highest was treatment 9 which had 4.45 cmol kg^{-1}, all treatments had reduction in rate as compared to the initial calcium rate of 4.75 cmol kg^{-1}.

In month 2 treatment 8 had 3.91 cmol kg^{-1} as the least, whiles treatments 5 had 4.10 cmol kg^{-1}. Treatment 1 had 4.11 cmol kg^{-1} and treatment

6 had 4.14 cmol kg^{-1}. Treatment 4 recorded 4.14 cmol kg^{-1} whiles treatment 3 had 4.26 cmol kg^{-1}, 4.37 cmol kg $^{-1}$ and 4.42 cmol kg^{-1} were had for treatments 2 and 7 respectively, and the highest was treatment 9 which had 4.45 cmol kg^{-1}, all treatments had reduction in rate as compared to the initial calcium rate of 4.75 cmol kg^{-1}.

In month 3 treatment 8 had 3.95 cmol kg $^{-1}$ as the least, whiles treatments 5 had 4.11 cmol kg^{-1}. Treatment 1 had 4.12 cmol kg^{-1} and treatment 6 had 4.14 cmol kg^{-1}. Treatment 4 had 4.17 cmol kg^{-1} whiles treatment 3 had 4.26 cmol kg $^{-1}$. 4.35 cmol kg $^{-1}$ and 4.42 cmol kg $^{-1}$ were had for treatments 2 and 7, and the highest was treatment 9 which had 4.45 cmol kg $^{-1}$, all treatments had reduction in rate as compared to the initial carbon rate of 4.75 cmol kg^{-1}. There was significant difference among the treatments.

In month 4 treatment 8 had 3.91 cmol kg $^{-1}$ as the least, whiles treatments 1 had 4.08 cmol kg^{-1}. Treatment 5 had 4.11 cmol kg $^{-1}$ and treatment 4 had 4.15 cmol kg^{-1}. Treatment 6 had 4.15 cmol kg^{-1} whiles treatment 3 had 4.26 cmol kg^{-1}. Treatments 2 and 7 had 4.37 cmol kg^{-1} and 4.39 cmol kg^{-1} respectively, and the highest was treatment 9 which had 4.44 cmol kg^{-1}, all treatments had reduction in rate as compared to the initial calcium rate of 4.75 cmolc kg^{-1}.

In month 5 treatment 8 had 3.95 cmol kg^{-1} as the least; whiles treatments 1 had 4.09 cmol k^{-1}. Treatments 6 had 5 had 4.14 cmol kg^{-1} respectively. Treatment 4 had 4.16 cmol kg^{-1} whiles treatment 3 had 4.25 cmol kg^{-1}, treatments 2 and 7 had 4.35 cmol kg^{-1} and 4.39 cmol kg^{-1} respectively, and the highest was treatment 9 which had 4.46 cmol kg^{-1}, all treatments had reduction in rate as compared to the initial calcium rate of 4.75 cmol kg^{-1}.

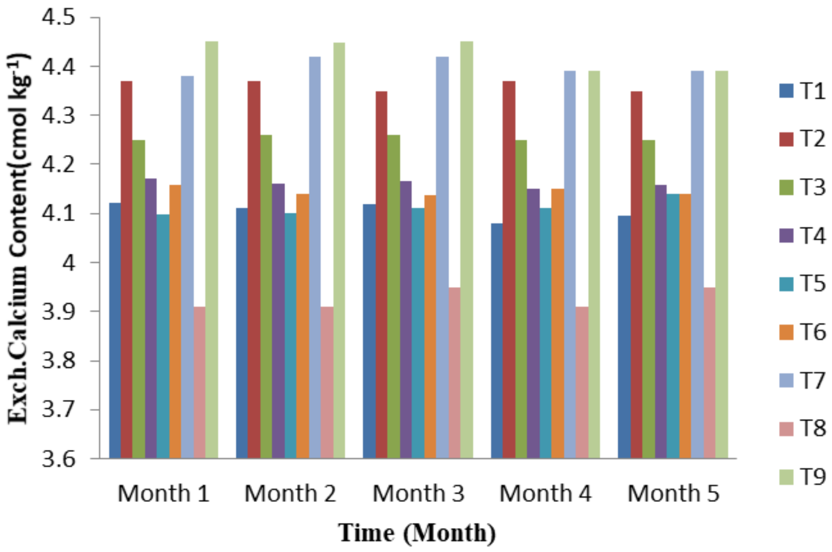


Figure 25: Calcium content in the soil as affected by the treatments.

Effect of treatments on exchangeable magnesium

Exchangeable Magnesium content in the soil was significantly ($p<0.05$) influenced by the treatments (Figure 26). The initial content of the soil was 2.24 cmol kg^{-1}. In month 1, treatment 8 had the least Magnesium content of 1.08 cmol kg^{-1}. Treatment 7 was 1.48 cmol kg^{-1} whiles treatments 4 and 3 had 1.53 cmol $kg^{-1}$and 1.61 cmol kg^{-1} respectively. Treatments 1 and 5 had 1.64 cmol $kg^{-1}$and 1.66 cmol kg^{-1}respectively. Both treatment 9 and 6 had 1.71 cmol kg^{-1}. The highest among the treatments was T2 which had 1.72 cmol kg^{-1}. This value was less than the initial magnesium content of 2.24 cmol kg^{-1}.

During the month 2, treatment 8 had the least Magnesium content of 1.13 cmol kg^{-1}. Treatment 7 was 1.48 cmol kg^{-1}whiles' treatments 4 and 3 had 1.51 cmol kg^{-1} and 1.62 cmol kg^{-1}respectively. Treatments 1 and 5 had 1.64 cmol $kg^{-1}$and 1.67 cmol kg^{-1}; whiles treatments 6 and 9 had 1.70 cmolc kg-

^{1}and 1.72 cmolc kg^{-1} respectively. The highest among the treatments was T2 which had 1.72 cmol kg^{-1}, less than the initial magnesium of 2.24 cmol kg^{-1}.

During the month 3, treatment 8 had the least Magnesium content of 1.08 cmol kg^{-1}. Treatment T7 had 1.48 cmol kg^{-1}, whiles treatment 4 had 1.53 cmol kg^{-1}., treatments 3, 1 and 5 had 1.61 cmol kg^{-1}, 1.64 cmol $kg^{-1}$and 1.66 cmol kg^{-1} respectively. Treatments 6, 9 and 2 had 1.71 cmol kg^{-1} and 1.72 cmol kg^{-1} the highest which is less than the initial magnesium of 2.24 cmolc kg^{-1} there was significant difference ($p<0.05$) among the treatments.

During the month 4, treatment 8 had the least Magnesium content of 1.09 cmol kg^{-1}. Treatment was T7 had 1.47 cmol kg^{-1}, whiles treatment 4 had 1.52 cmol kg^{-1}, and treatments 3, 1 and 5 had 1.60, 1.63 and 1.66 cmol (+) kg-1 respectively. Treatments 6, 9 and 2 had 1.70 cmol kg^{-1} and 1.72 cmol kg^{-1}respectively. Magnesium contents in all the treatments were lower than the initial content of cmol kg^{-1}.

During the month 5, treatment 8 had the least Magnesium content of 1.15 cmolc kg^{-1}. Treatment T7 1.49 cmol kg^{-1} whiles treatment 4 had 1.53 cmol kg^{-1}. Treatments 1 and 3 had 1.61 cmol kg^{-1} and 1.62 cmol kg^{-1} respectively. Treatment 5 and 6 had 1.67 cmol kg^{-1}, 1.68 cmol kg^{-1} respectively. Treatments 2 and 9 had 1.68 cmol kg^{-1} and 1.71 cmol kg^{-1} (the highest). All treatments showed less magnesium contents than the initial content of 2.24 cmol kg^{-1}. There were significant differences ($p< 0.05$) among the treatments. The percentages calculated for the last month shows differences from the foliar to the granular fertilizers. The organic granular had the highest percentages of 12% to 33 for treatments 7 & 8. The organic foliar was -2% for both treatments 5&6. The inorganic was -5 to -11 for treatments

3&4 and treatments 1 &2 was -6 and -2 respectively all against the control without any amendments.

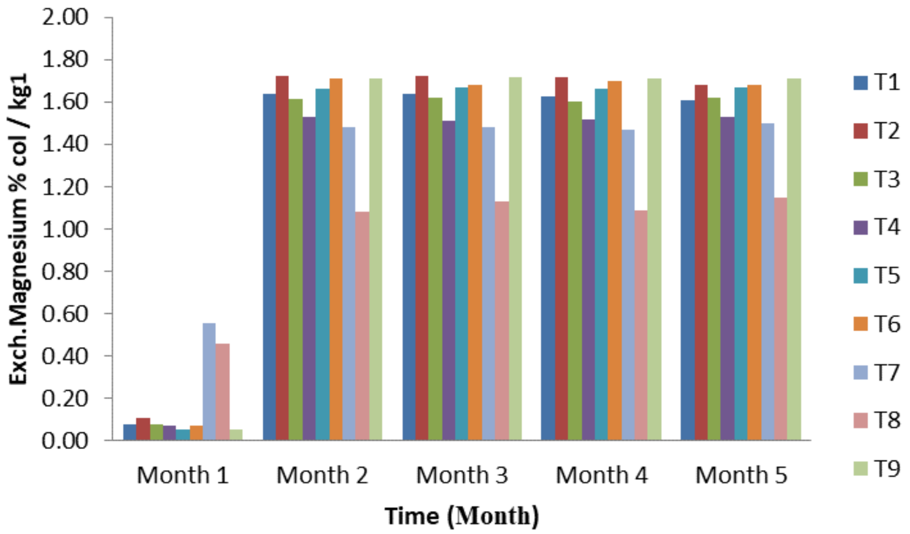


Figure 26: Magnesium in the soil as affected by the treatments.

Quality cocoa seedling growth is usually dependent on the potting media in which the seedlings are raised. Application of organic fertilizer mineralizes and releases nutrients to the soil as Green OK and Elite both foliar and granular. From the initial soil test results, available phosphorus level was 19.38 mg/kg which was lower than the optimum level of above 20 mg/kg required for cocoa cultivation (Egbe, Ayodele, & Obatolu, 1989; Ogunlade, Adeoye, Ipinmoroti, Ibiremo, & Iloyanomon, 2006). Mechanical analyses indicated that the soils had high sand content and this has implication on their ability to retain moisture and the release of plant nutrients.

The foliar fertilizer Sidalco and the organic granular Elite fertilizer showed higher height at the end of the trial as discussed, also observed in Ofori-Frimpong (2006), Shepherd, Davis and Johnson (1993), Ogunlade

(2006) and Bergmann (1992) for vigorous hybrid cocoa with adequate shade and all nursery requirement met.

The foliar fertilizer Sidalco and the organic granular Elite fertilizer showed higher stem diameter as was also observed by Arthur (2009) and Asare and David (2010). In dry matter production, the greatest proportion was in the leaves, followed by the stem and then the roots. This is somehow contrary to the findings of Owusu-Aduomi and Frimpong (1985), who found the greatest dry matter yield in the stem followed by the leaves and then the roots.

For soil nutrients uptake, healthy seedling growth is usually dependent on the potting media in which the seedlings are raised. Organic carbon content in Wacri series is very low. This is because the values obtained were below the 3% considered adequate for good cocoa growth (Ahenkorah, 1981). The low organic carbon of the Wacri series meant that nutrient supply to the seedlings would be difficult. Nitrogen content of the Wacri series was higher than the critical level of 0.09 % required for cocoa cultivation (Ahenkorah, 1981; Egbe, Ayodele, & Obatolu, 1989). Wacri soil series had the least mean available phosphorous concentration and was lower than the optimum level of above 20 ppm required for cocoa cultivation (Egbe et al., 2006). Mechanical analyses indicated that the soils have high sand content and this has implication on their ability to retain moisture and the release of plant nutrients. The pH of the soils changed with the incorporation of the soil amendments. The addition of Green OK organic foliar media improved the fertility status of the less fertile Wacri series. This finding was similar to that of Moyin-Jesu (2007) who reported the nutrient superiority of organically amended fertilizers compared to the ordinary forms of the materials. Arthur et al. (2019) also found an improvement in soil chemical properties. Application of organic fertilizer mineralizes and releases nutrients to the soil. The reduction in soil pH following the application of the NPS fertilizer could be attributed to the acidifying effect of sulphate of ammonia in the formulation (McCauley, Jones, & Olson, 2017).

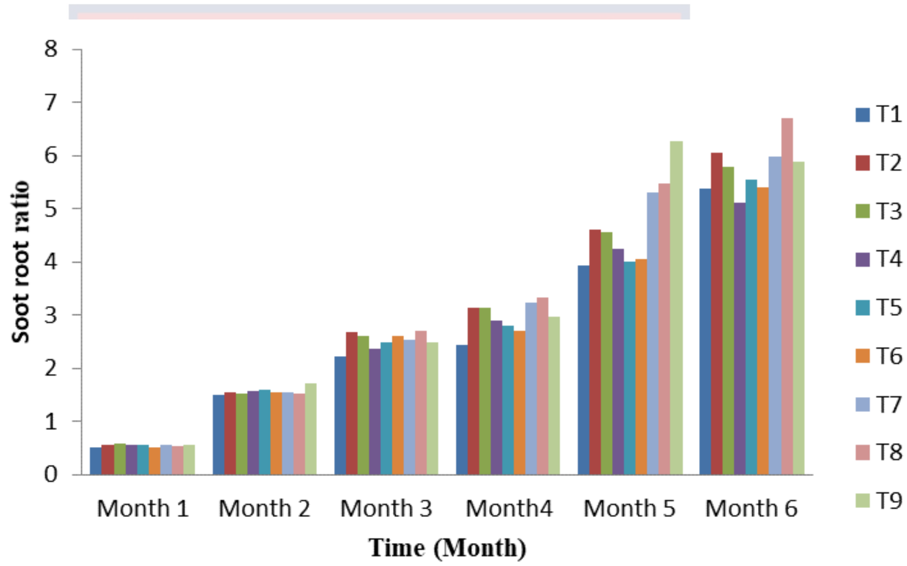


Figure 27: Shoot: root ratio of cocoa seedlings as affected by fertilizer treatments

Shoot and root ratio was significantly ($p < 0.05$) different at the end of the month 6. In month 1 treatment 3 NPS level one was the highest and the least was treatment 1 Sidalco level one. Month 2 recorded treatment 9 control as the highest and the least was the Sidalco level one treatment. The month 3 recorded treatment Elite organic level two as the highest followed by treatment 2 Sidalco level two and the least was treatment 1 Sidalco level one. The month 4 recorded treatments 8 Elite level two and level one for the first and second respectively and the least was Sidalco level one treatment 1. The month 5 recorded treatment 9 control as the highest and the least was treatment 1 Sidalco level one. In month 6 treatments 8 Elite organic granular recorded the highest and followed by treatment 2 Sidalco level two as the second and the least was treatment 4 NPS inorganic granular fertilizer level two. NPS made the soil more acidic when it is doubled.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Growth of healthy cocoa seedling is usually dependent on the potting media in which the seedlings are raised. This study evaluated the growth of cocoa seedlings using different soil and foliar amendments at the nursery.

The study is to address the issue of suitable fertilizer formulations for nursing cocoa at the nursery. Elite organic granular fertilizer performed better during the trial by producing high dry matter yield whilst Green OK, the organic foliar fertilizer, produced low dry matter yield among the treatments. Elite organic fertilizer, Sidalco foliar fertilizer, NPS and Green OK were first, second, third and fourth in terms of dry matter production respectively. Considering the need to alternatively look for ways of raising more vigorous cocoa seedlings for farm establishment, this has paved way for the use of organic and inorganic fertilizers to readily make available to the plant soil nutrients necessary for better cocoa seedling growth. The organic granular Elite fertilizer double dose or level two was the best among the treatments. Sidalco inorganic fertilizer level two was the second-best whiles CSIR NPS inorganic granular was the third and Green OK was the fourth which performed less among all the treatments. The soil physico-chemical properties show pH was reducing in terms of the fertilizers used especially NPS reduced drastically as low as 4.79 which show it cause soil acidity. Sidalco was the second which at the end of the fifth month was around 5.57 slightly acidic but organic fertilizers pH was around 6.2 for Elite and Green OK. Control was less around 6.6 almost neutral. Elite and Sidalco performed well during the trial as compared to the control, NPS and Green OK in the plant height, stem diameter, number of leaves and dry matter yield of the double dose then the single dose. NPS single dose performed better than the double dose, Green OK was both were not impressive during the trial.

Conclusions

The project work, which was aimed at finding out if there could be an alternative means of raising cocoa seedlings in the absence of nutrient rich top soil, was a successful one. The nine (9) soil media tested in the trial (treatments) produced significant differences in the results (plant growth parameters and the soil physico-chemical properties). The study showed that different plant growth media can affect or enhance the growth of cocoa seedlings making them robust and ensures vigorous growth of the seedlings during transplanting. The strategies adopted in the selection of the fertilizers and soil amendments were based on the different types or groups of the fertilizers to serve as candidate fertilizers for the different groups and types. Sidalco liquid fertilizer was a foliar type, Elite was an organic type, N: P: S 14-31-0-S was the conventional inorganic and Green OK was organic foliar. Applications of each of the fertilizers were doubled to check for toxicity if possible. Although these affected the growth parameters differently, it came out clearly that Elite organic fertilizer had much influences on most of the growth parameters and was followed by Sidalco liquid fertilizer. It was clear that the conventional inorganic fertilizer, N: P: S 14-31-0-S most often than not had less effect on enhancing growth parameters. Green OK though being foliar, had less effect possibly as a result of its nutrient content and formulation. From this study, it could be noted that although treatment 9 which served as the control (without fertilizer) improved in some of the growth parameter than the treatments with fertilizer. It was noted that the soil pH kept on reducing with the application of the N: P: S 14-31-0-S making the soil environment rather less conducive for the seedlings growth and development. Although this particular inorganic fertilizer did not work well it may be possible that a fertilizer which may easily cause acidity may do better than this.

Although there are a lot of information attesting to the fact that nutrients support for cocoa seedling growth is coming from the cotyledons this trial also points to the fact that at least some are coming from other sources apart from the cotyledons. I finally conclude that in establishing a nursery for raising cocoa seedlings, the Elite fertilizer could be applied twice the dosage or even at a single dose since no economic analysis of the application was carried out to show which application rate was more economically viable. In a similar situation, Sidalco liquid fertilizers at both dosages are recommended for application. Green OK may not help much while the N: P: S 14-31-0-S should not be used as a result of its acidic effects. Cocoa seedling will respond effectively to fertilizer applications if the management factors, soil and climatic conditions are favourable for good growth and if the soils cannot supply the nutrients required on time organic and inorganic supplements will be used as both foliar and granular fertilizers to produce vigorous seedlings. This is in view of the strong interaction between nutrients and the management factors to produce strong growth and healthy cocoa seedlings. Using of fertilizer will help increase growth of cocoa seedling and give a healthy strong cocoa to boost the nation economic stability especially organic fertilizers that will not affect the environment. From the research conducted Elite organic granular fertilizer and Sidalco foliar fertilizer did perform well in most of the parameters taken in height, stem diameter, shoot root ratio and number of leaves were improved then the control expects in dry matter yield of the root.

Recommendations

It is recommended that Elite organic fertilizer and Sidalco foliar fertilizer could be applied to potting media in the raising of cocoa seedlings. N-P-S-14-31-0-S and Green OK from the trials were not suitable for raising the seedlings as most of the growth parameters were not enhanced. Soil – physio chemical properties were also affected negatively. Although the inorganic fertilizer did not perform well and caused acidity, future experiments could target on inorganic conventional fertilizers that will not affect the pH of the soils. Considering the application rates the next experiment could have increase in the number of application rates to study the trend of increasing the concentrations of the fertilizer in the potting media. The economic analysis could be studied to identify the viability of choosing the rates of the application. The next experimental could also go beyond the six months to study if the growth patterns of the seedlings could change after the six months.

It is recommended that the Elite organic fertilizer for COCOBOD, cocoa nursery operators, MoFA and NGOs in cocoa nursery business. Elite granular fertilizer did well among most of the treatments but its application is very tedious so for further research work I recommend the foliar type of Elite organic fertilizer because it was used on matured cocoa and the result was really impressive. Further research work should be conducted on the use of Elite fertilizer for organic cocoa farming to minimise soil acidity. Also, further studies could be conducted on nursing cashew, coffee and kola seedlings with the Elite organic granular fertilizer.

REFERENCES

Adejobi, K. B., Akanbi, O. S., Ugioro, O., Adeosun, S. A., Mohammed, I., Nduka, B. A., & Adeniyi, D.O. (2013). Comparative effects of NPK fertilizer, cowpea pod husk and some tree crops wastes on soil, leaf chemical properties and growth performance of cocoa (*Theobroma cacao* L.). *African Journal of Plant Science*, *8*(2), 103-107.

Adu, S. V., & Mensah-Ansah, J. A. (1969). *Classification of Ghanaian soils for cocoa rehabilitation. Conference paper* (No. 39, p. 15). Ghana, Soil Research Institute.

African Union (2006). *Declaration on fertilizer for the African Green Revolution. At the African Union Special Summit of the Heads of States and Governments*. 21st September, 2009. Abuja, Nigeria.

Afrifa, A., Ofori-Frimpong, K., Acquaye, S., Snoeck, D., Abekoe, M., (2010). Soil nutrient management strategy required for sustainable and competitive cocoa production in Ghana. pp 335-342.

Ågren G. I., Ingestad T. **(**1987)**.** Root-shoot ratio as a balance between nitrogen productivity and photosynthesis. *Plant Cell and Environment 10*, 579–586.

Ågren G. I., Wikström J. F. (1993)**.** Modelling carbon allocation - A review. *New Zealand Journal of Forestry Science 23, 343–353*.

Ahenkorah Y., Halm B., Appiah M. R., & Akrofi G. (1982*). Fertilizer use on cacao rehabilitation projects in Ghana.* Proceedings of the 8th International Cocoa Research Conference, Cartagena, Colombia, 18 23 Oct 1981. Cocoa Producers' Alliance, pp. 165–170.

Ahenkorah, Y. (1981). *The influence of environment on growth and production of the cacao tree: soils and nutrition*. Proceedings of the 7th International Cocoa Research Conference, 1979, Douala, Cameroon, pp 167 – 176.

Aikpokpodion, P. (2010). Nutrients dynamics in cocoa soils leaf and beans in Onto state, Nigeria. *Journal of Agricultural Sciences, 1*(1), 1–9.

Akanbi, O. S., Ojeniyi, S. O., Famaye, A. O., Ipinmoroti, R. R, Oloyede, A. A., Oyewumi, I. K., Ayegbonyin, K., Adejobi, K. B., & Idrisu, M. (2014). Soil nutrients and cocoa seedling performance as influenced by plant residue ash and NPK fertilizer addition on a depleted soil in Ibadan, South Western, Nigeria. *Int. Res. J. Agric. Sci. Soil Sci. 4*(1), 1-4.

Ali, F. M., (1969). Effects of rainfall on yield of cocoa in Ghana. *Experimental Agriculture, 5*, 209-213.

Alvenson, W. S., Whitlock, B. A., Feller, R., Bayer, C., Baum, D. A., (1999). Phylogeny of the Core Malvales; Evidence from ndhf. Sequence Data. *In American Journal of Botany, 86*, 474 – 486.

Anim-Kwapong, G. J., & Frimpong, E. B. (2005). *Vulnerability of agriculture to climate change: Impact of climate change.* New Tafo Akim, Cocoa Research Institute of Ghana. Retrieved from http://www.nlcap.net/fileadmin/NCAP/Countries/Ghana/COCOA on 02/09/09.

Anthonio, M. M., Boampong, E. Y., Coleman, F. N., & Anthonio, F. A. (2018). The Impact of different growth media on cocoa *(Theobroma cacao L.)* seedling. *JENRM, 5*(1), 1-4.

Appiah, M. R., Ofori-Frimpong, K., & Afrifa, A. A., (2000). Evaluation of fertilizer application on some peasant cocoa farms in Ghana. *Ghana Journal Agric. Science, 33*, 183- 190.

Appiah, M. R., Sackey, S. T., Ofori-Frimpong, K. & Afrifa, A. A., (1997). The consequences of cocoa production on soil fertility in Ghana: A review. *Ghana Journal Agric Science*, *30*,183 – 190.

Arthur, A., (2009). *Effect of decomposition crop residues on soil property and crop productivity in the sub-deciduous forest zone of Ghana*. Unpublished doctoral thesis submitted to Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Arthur, A., Dogbatse, J. A., Quaye, A. K., & Konlan, S. (2019). Effect of municipal solid waste compost on soil chemical properties and growth performance of cocoa (*Theobroma cacao* L.) seedlings at the nursery in Ghana. *Intl J. Plant Soil Sci., 28*(2), 1-8.

Asare, R., & David, S. (2010). *Planting, replanting and tree diversification in cocoa systems*. *Learning about sustainable cocoa production: a guide for participatory farmer training*. *Manual No. 2. Development and Environment Series. 13-2010*, Forest and Landscape. Denmark.

Asomaning, E. J. A., Kwakwa, R. S., & Hutcheon, W. V. (1971). Physiological studies on an Amazon shade and fertilizer trial at the Cocoa Research Institute of Ghana. *Ghana Journal of Agricultural Science, 4, 47-64.*

Ayeni, L. S. (2008). Integration of Cocoa Pod Ash, poultry manure and NPK 20:10:10 for soil Fertility Management – incubation study. *Cont. J. Agron*, *2*, 25 -30.

Baah, F. (2008) Harnessing farmer associations as channels for enhancing management of cocoa holdings in Ghana. *Scientific Research and Essay*, *3*, 395-400.

Baldock, J. A., & Skjemstad, J. O. (1999). Soil organic carbon/soil organic matter. In K. I. Peverill, L. A. Sparrow & D. J. Reuter (Eds). *Soil Analysis: An Interpretation Manual* (pp. 159-170). CSIRO: Collingwood.

Barrientos, S. W., Asenso-Okyere, K., Assuming-Brempong, S., Sarpong, D., Anyidoho, N. A., & Kaplinsky, R. (2008). *Mapping sustainable production in Ghanaian cocoa* (A report to Cadbury). Institute of Development Studies and the University of Ghana.

Bayala, J., Mandob, A., Teklehaimanotc, Z., & Ouedraogoa, S. J., (2005). Nutrient release from decomposing leaf mulches of karate (*Vitellaria paradoxa*) and nere (*Parkia biglobosa*) under semiarid conditions in Burkina Faso, *West Africa. Soil Biology and Biochemistry*, *37*, 533–539.

Bearden, M. M., Keen, C. L., & Steinberg, F. M., (2003). Cocoa and chocolate flavonoids: Implications for cardiovascular health. *Journal of the American Dietetic Association*, *103*(2), 215–223. doi: 10.1053/jada.2003.50028.

Benbi, D. K., Biswas, C. R., Bawa, S. S., & Kumar, K., (1998). Influence of farmyard manure, inorganic fertilizers and weed control practices on some soil physical properties in a long-term experiment. *Soil Use and Management*, *14*, 52–54.

Bergmann, W. (1992). *Nutritional disorders of plants* (2nd ed.). Gustav Fischer Verlag, Jena, Germany.

Binam, J. N., Gockowski, J., & Nkamleu, G. B. (2008). Technical efficiency and productivity potential of cocoa farmers in West African countries. *The Developing Economies*, *46*(3), 242-263.

Bloom, A. J., Chapin III, F. S., & Mooney, H. A. (1985). Resource limitation in plants-an economic analogy. *Annual Review of Ecology and Systematics*, *16*(1), 363-392.

Bouyoucos, G. H. (1951). A recalibration of the hydrometer for making mechanical analysis of soils. *Agronomy Journal*, *43*, 434 – 438.

Brady, N. C., & Weil, R. (1999). *The nature and properties of soils*. (12th ed.). London.

Bremner, J. M. (1965). Total nitrogen. In C. A. Black (Ed.). *Methods of soil analysis: Part 2: Chemical and microbiological properties* (pp. 1149-1178). American Society of Agronomy, Madison.

Brew, K. M. (1988). Relationship between yield, rainfall and total sunshine hours. *Rep. Cocoa Research Institute of Ghana*, *89*, 30-32.

Cannell, M. R., & Dewar, R. C. (1994). Carbon allocation in trees: a review of concepts for modelling. *Advances in Ecological Research*, *25*, 59-104.

Cocoa Research Institute of Ghana (CRIG) (1987). *A guide to cocoa production*. Cocoa Research Institute of Ghana, Ghana. Cocoa Board, Accra, Ghana. p 3,4,13.

COCOBOD (2001). Supply chain risk assessment report. 3-7p. In E. Crawford, T. S. Jayne, & V. Kelly (Eds.). *Alternative approaches for* *promoting fertilizer use in Africa*. Agriculture and Rural Development Discussion Paper 22, World Bank, Washington, D .C.

Donkor, M. A., Henderson, C. P., & Jones, A. P. (1991). Survey to quantify adoption of CRIG recommendations. *Farming Systems Unit Research Paper*, *3*, 29. Tafo. Cocoa Research Institute, Ghana.

Doran, J. W., Sarrantonio, M., & Liebig, M. A. (1996). Soil health and sustainability. *Advances in Agronomy, 56*, 1–54.

Egbe, N. E., Ayodele, E. A., & Obatolu, C. R. (1989). Soils and nutrition of cocoa, coffee, kola cashew and tea. *Programme Tree Crop Res*earch, *2*, 28-38. *CRIN*, Ibadan.

Ericsson T. (1995) Growth and shoot: Root ratio of seedlings in relation to nutrient availability. In L. O. Nilsson, R. F. Hüttl & U. T. Johansson (eds) *Nutrient uptake and cycling in forest ecosystems*. *Developments in plant and soil sciences*, Volume 62 (pp. 205-214) Springer, Dordrecht. https://doi.org/10.1007/978-94-011-0455-5_23.

Fagbohun E., Anibijuwon I., Oluwole E. & Opeyemi L., (2011). Fungi associated with spoilage of dried cocoa beans during storage in Ekti State of Nigeria. *Journal of Microbiology, Biotechnology and Food Sciences, 1* (2), 204-214.

Fahmy, F. N. (1980). *Soil and leaf analyses in relation to the nutrition of tree crops in Papua New Guinea*. Paper presented at Conference on classification and management of Tropical Soils, Kuala Lumpur, Malaysian Society of Soil Science, 15-20 August, 1977.

FAO. **(**1999). *Integrated soil management in Southern and East Africa.* AGL/MISC/23/99. Rome.

FAOSTAT (2012). Food and agricultural organisation. *World Food Balance sheet.* Retrieved from www.faostat. fao.org.

Fatunbi, A.O., & Ncube, L., (2009). Activities of effective microorganism on the nutrient dynamics of different organic materials applied to soil. *American-Eurasian Journal of Agronomy*, *2*(1), 26 - 35.

Fidelis, C., & Rao, B. R. (2017). Enriched cocoa pod composts and their fertilizing effects on hybrid cocoa seedlings. *International Journal of Recycling of Organic Waste in Agriculture*, *6*(2), 99-106.

Galyuon, I. K. A., McDavid, C. R., Lopez, F. B., & Spence, J. A. (1996). The effect of irradiance level on cocoa (Theobroma cacao L.) II. Gas exchange and chlorophyll fluorescence. *Tropical Agriculture*, *73*(1).

GenStat (2008). Lawes agricultural trust *(Rothamsted Experimental Station); (2008)*. Retrieved from: http://www.vsni.co.uk.

Ghana Statistical Service (2015). *Annual Gross Domestic Produc*t. Retrieved https://statsghana.gov.gh/gssmain/fileUpload/National%20Accounts/2015AnnualGDP September2015 Edition.pdf.

Gockowski, J., Weise, S., Sonwa, D., Tchatat, M., & Ngobo, M. (2004). Conservation because it pays: shaded cocoa agroforests in West Africa. *National Academy of Sciences in Washington DC on February*, *10*, (29).

Goyal, S., Mishra, M.M., Hooda, I. S., & Singh, R., (1992). Organic matter microbial biomass relationships in field experiments under tropical conditions: effects of inorganic fertilization and organic amendments. *Soil Biology and Biochemistry*, *24*, 1081–1084.

Hala, I., C., Zibilske, L. M., & Tsutomu, O. (2003). Effects of earthworm casts and compost on soil microbial activity and plant nutrient availability. *Soil Biology and Biochemistry*, *35*, 295–302.

Hanak-Freud E., Petithuguenin P., & Richard J. (2000). Les champs du cacao: un défi de compétitivité *Afrique-Asie*. Montpellier, France.

Hanway, J. J., & Heidel, H., (1952). Soil analysis methods as used in Iowa State College Soil Testing Laboratory. *Iowa Agri*, *57*, 1 – 31.

Hartemink, A. E., (2005). Nutrient stocks, nutrient cycling and soil changes in cocoa ecosystem: A review. *Adv. Agron.*, *8*, 227-253.

Hebel, A. (1994). Soil Characterization and evaluation system (SCE) with emphasis on top soils and their fertility-related characteristics. *Food and Agriculture Organization of the United Nations, Rome*.

Hilbert D. W. (1990). Optimization of plant root: Shoot ratios and internal nitrogen concentration. *Annals of Botany*, *66*, 91–99.

Hills, A., Miller, E., & Miller, A. (2000). Management of soil acidity in agricultural land [Western Australia]: Farm note 80/2000 Agriculture Western Australia. *Lake Grace*.

Hurd, R. G., & Cunningham, R. K. (1961). A cocoa shade manurial experiment at the West African Cocoa Research Institute. III. Physiological results. *Journal Hort. Sci.*, *36*, 1326-1337.

Hutcheon, W. V. (1977). *Growth and photosynthesis of cocoa relation to environmental and internal factors.* Proceedings 5th International Cocoa Research Conference, Ibadan, Nigeria, pp. 222-223.

Ingestad T., & Ågren, G. I. (1991). The influence of plant nutrition on biomass allocation. *Ecological Applications*, *1*,168–174.

Institute of Social, Statistical and Economic Research (ISSER) (2008). *The state of the Ghanaian Economy in 2007*. ISSER, University of Ghana, Legon, Accra.

International Fertilizer Industry Association (IFA). 1992. *World fertilizer use manual.* Paris. pp.632.

International Monetary Fund (IMF), (2007). *Online Database. International Financial Statistics.* Retrieved from http://www.imfstatistics.org/imf on 12th October, 2007.

Jerome, A. D., Arthur, A., Amoako-Attah, I., Quaye, A. K., Konlan. S, Owusu-Ansah F., Djan E., & Amon-Armah, F. (2019). Growth response of Cocoa (*Theobroma cacao* L.) seedlings to application of cocoa pod husk-based compost. *International Journal of Plant and Soil Science, 31*(2), 1-13.

Johnson I. R., & Thornley, J. H. M. (1987). A model of shoot: root partitioning with optimal growth. *Annals of Botany*, 60, 133–142.

Katz, D., Doughty, K., & Ali, A. (2011). Cocoa and chocolate in human health and disease. *Antioxidants and Redox Signaling, 15*(10), 2779-2811. doi:10.1089/ars.2010.3697.

Koko, L. K., (2014). Teractiv cacao as a new fertilizer based reactive phosphate rock for cocoa productivity in Côte d'Ivoire: A participatory approach to update fertilization recommendation. *Procedia Eng. 83*, 348-353.

Kolota, E., & Osinska, M. (2001). Efficiency of foliar nutrition of field vegetables grown at different nitrogen rates. In: Proc. *International Conference on Environmental Problems associated with Nitrogen*

Fertilization of field grown vegetable crops 563 (pp. 87–91). Macmillan.

Kolota, E., & Osinska, M. (2001). Efficiency of foliar nutrition of field vegetables grown at different nitrogen rates. *Acta Hortic*. *563*, 87-91. doi:10.17660/ActaHortic.2001.563.10 https://doi.org/10.17660/ActaHortic.2001.563.10

Lockwood, R.G., & Asomaning, E. J. A. (1963). Physiology of cocoa. *Rep. West Africa Cocoa Res. Inst.* pp. 56 -57.

McCauley, A., Jones, C., & Olson-Rutz K., (2017). *Soil pH and Organic Matter. Nutrient Management Module 8.* Montana State University Ext, pp 16.

Mehta, S. (2013). Pharmacognosy and health benefits of cocoa seeds (chocolate) Notes. *Pharmacognosy*, *6*.

Mensah-Brako, B. (2011). *Effect of watering regime and cocoa pod husk on soil fertility and growth of hybrid cocoa seedlings in the semi-deciduous forest zone of Ghana*. Unpublished master's thesis submitted to Kwame Nkrumah University of Science and Technology, Kumasi.

MOFA (Ministry of Food and Agriculture). (2008). *Highlight on fertilizer subsidy policy implementation strategy*. Ministry of Food and Agriculture, Statistics, Research and Information Directorate, Accra, Ghana.

Mohd,Y. A. S., Ahmad, K. M. J., & Hamzah, D. (2007). The effect of various rates of phosphate application on the growth of cocoa seedlings and its nutrient uptake in relation to chemically available phosphorus in the soil and age of seedling. *Malaysian Cocoa* Journal, *3*,1-12.

Monteith, J. (1978). Reassessment of maximum growth rates for C3 and C4 crops. *Exp. Agric*. *14*, 1-5.

Morris, M., Kelly, V., Kopicki, R., & Byerlee, D. (2007). *Fertilizer use in African Agriculture: Lessons learned and good practice guidelines*. Agriculture and Rural Development Division, World Bank, Washington, DC.

Mossu G. (1992*). Cocoa. Tropical Agriculturalist Series, Technical Centre for Agricultural and Rural Cooperation.* Macmillan Press, London, United Kingdom.

Moyin-Jesu, E.I. (2007). Effects of some organic fertilizers on soil and coffee (*Coffee Arabica* L), leaf chemical composition and growth. University of Khartoum. *Journal of Agric. Sci. 15*(1), 52-70.

Murray, D. B. (1967). Leaf analysis applied to cocoa. *Cocoa Growers' Bulletin*, *9*, 25-31.

Nath, R. T., & Yadav, J. A. (2011). Influence of inorganic and organic nutrient sources on soil enzyme activities. *Journal of the Indian Society of Soil Science, 59*(1), 54–59.

Nkamleu, G. B., Nyemeck, J., & Gockowski, J. (2010). *Technology gap and efficiency in cocoa production in West and Central Africa: Implications for cocoa sector development. African Development Bank, Cote d'Ivoire.*

Odedina, S. O., Awodun, M., & Ojeniyi, S. O. (2007). Effect of cocoa husk on the soil fertility, leaf mineral composition and growth of tomatoes. *Global Journal of Environmental Studies*, *26*(1), 6-12.

Ofori-Frimpong, K., Afrifa, A. A., & Acquaye, S. (2010). Relative efficacy of cocoa pod husk-based compost on growth and nutrient uptake of cocoa seedlings in the nursery. *Ghana Journal of Agricultural Science*, *43*,1.

Ofori-Frimpong, K., Afrifa, A. A., & Appiah, M. R. (2006). Improving the growth of cocoa seedlings in nursery by the use of fertilizers. *Journal of Ghana Science Association*, *8*(2), 85-91.

Ogunlade, M. O. (2008). *Seedling establishment under old cocoa plantation using neem-fortified cocoa pod husk fertilizer at Ibadan and Owena, South Western Nigeria*. Unpublished doctoral thesis submitted to Department of Agronomy, University of Ibadan, Nigeria.

Ogunlade, M. O., & Aikpokpodion, P. O. (2006). Available phosphorus and some micro-nutrient development, contents of cocoa soils in three cocoa growing ecological zones of Nigeria. In *Proceedings of 15th International Cocoa Research Conference* (pp. 675–678). San José, Costa Rica, 9–14 October, 2006.

Ogunlade, M. O., Adeoye, G. O., Ipinmoroti, R. R., Ibiremo, O. S., & Iloyanomon, C. I. (2006). Comparative effects of organic and NPK fertilizers on the growth and nutrient uptake of cocoa seedlings. *Nigerian Journal of Soil Science, 16* (1), 92-98.

Ogunlade, M., Oluyole, K., & Aikpokpodion, P. (2009). An evaluation of the level of fertilizer utilization for cocoa production in Nigeria. *Journal of Human Ecology, 25*(3), 175–178.

Opoku S.Y., Padi, F. K., Adomako, B., Adu-Ampomah, Y. (2010). Effectiveness of juvenile tree growth rate as an index for selecting high yielding cacao families. *Sci Hortic, 139, 14–20.*

Opoku-Ameyaw, K., & Appiah, M. R., (2000). Improving the growth of cashew (Anacardium occidentale) seedlings interplanted into mature sheanut stands in northern Ghana. *Ghana Journal of Agricultural Science*, *33*(2), 159-164. doi:10.4314/gjas.v33i2.1865.

Opoku-Ameyaw, K., Baah, F., Gyedu-Akoto, E., Anchirinah, V., Dzahini-Obiatey, H., & Cudjoe, A. R. (2010). *Cocoa manual: A source book for sustainable cocoa production*. New Tafo-Akim, Ghana. Cocoa Research Institute of Ghana (CRIG), (Ghana Cocoa Board).

Oppong, F. K., Ofori-Frimpong, K., & Fiakpornu, R. (2008). Effect of polybags size and foliar application of urea on cocoa seedling growth. *Ghana Journal of Agricultural Science, 40,* 207-213.

Oro, Z. F. (2011). *Spatial dynamics and molecular epidemiology analysis of swollen shoot disease of cacao-trees in Togo*. Unpublished doctoral thesis of Agronomy Sciences submitted to Ecole Nationale Supérieure d'Agronomie de Montpellier, SUPAGRO.

Owusu-Aduomi, K., & Frimpong E. B. (1985). *Pattern of dry matter partitioning in cocoa. Rep. Cocoa Res. Inst.*, 1979/80-1981/82,176

Oyewole, O. S., Ajayi, O. J., & Rotimi, R. I. (2012). Growth of cocoa (*Theobroma cacao* L.) seedling on old soils amended with organic and inorganic fertilizer. *African Journal of Agricultural Research, 7*(24), 3604-3608.

Pagel, H., Enzmann, J., & Mutscher, H. (1982) Plant nutrients in tropical soils-their determination and evaluation. *VEB German Agricultural Publishing*, Berlin.

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G., Giller, K. E. (2001). Organic inputs for soil fertility management in tropical agro ecosystems: application of an organic resource database. *Agriculture Ecosystems Environment*, 83, 27- 42.

Peprah, K., Amoah, S. T., & Akongbangre, J. N. (2019). A review of practices for sustaining urban and peri-urban agriculture: Implications for land use planning in rapidly urbanising Ghanaian cities. *Land Use Policy, 84*, 260-277. https://doi.org/10.1016/j.landusepol.2019.03.004.

Posch, M., KÄmÄri, J., Forsius, M., Henriksen, A., & Wilander, A. (1997). Environmental auditing: exceedance of critical loads for lakes in Finland, Norway, and Sweden: reduction requirements for acidifying nitrogen and sulfur deposition. *Environmental management*, *21*(2), 291-304.

Quaye, A. K., Konlan, S., Arthur, A., Pobee, P., & Dogbatse, J. A., (2019). Effect of media type and compost mixtures on nutrient uptake and growth of cocoa (*Theobroma cacao L.)* seedling in the nursery. *Ghana Journal of Horticulture (JHORT, 14*(1), 11-21.

Raja, H. R. M., & Hardwick, K. (1986). Photosynthesis and transpiration of cocoa leaves. In E. Pushparajah & P. S. Chew (eds.) *Cocoa and coconuts: Progress and outlook* (pp. 499-504). Incorporated Society of Planters, Kuala Lumpur.

Raja, H. R. M., & Hardwick, K. (1988). The effect of different temperatures and water vapour pressure deficits on photosynthesis and transpiration of cocoa leaves. In Proceedings of the 10th International Cocoa Research Conference, pp 211–214.

Ramesh, P., Panwar, N. R., Singh, A. B., Sivakoti, R., & Subba, R. A. (2009). Impact of organic-manure combinations on the productivity and soil quality in different cropping systems in central India. *Journal of Plant Nutrition and Soil Sciences, 172*, 577–585.

Rhodes, E. R. (1995). Nutrient depletion by food crops in Ghana and soil organic nitrogen management. *Agric. Syst*, *48*(1), 101-118.

Ruf, F. (2007). *The new Ghana cocoa boom in the 2000s from forest clearing to green revolution report*. Ministry of Finance and Economic Planning, Accra, Ghana.

Shepherd, M. A., Davis, D. B., & Johnson, P. A., (1993). Minimizing nitrate losses from arable soils. *Soil Use and Management*, *9*(3), 96–99.

Singh, C., & Sharma, B. B. (1993). Leaf nutrient composition of sweet orange as affected by combined use of bio and chemical fertilizers. *South Indian Horticulture*, *41*, 131-131.

Skidmore, C. L. (1929). Indications of existing correlation between rainfall and the number of pods harvested at Aburi and Asuansi. Department of Agriculture Gold Coast. *Bulletin*, pp.114-120.

Smellie, T. J. S. (1925). Rainfall and cocoa yields. *Tropical Agriculture*, *2*, 160.

Snoeck D., Abekoe, M. K., Afrifa, A. A., & Appiah, M. R. K., (2006). The soil diagnostic method to compute fertilizer requirements in cocoa plantations, *Proceedings of the International Conference of Soil Science.* 10p.

Sosu, G. (2014). *Growth of cocoa seedlings as affected by different growth media and different polybag sizes*. Unpublished doctoral thesis submitted to University of Ghana.

Teal, F., Zeitlin, A., & Maamah, H. (2006). *Ghana cocoa farmers survey 2004*: *Report to Ghana Cocoa Board. Centre for the Study of African Economies,* Accra.

Thornley J. H. M. (1972). A balanced quantitative model for root: shoot ratios in vegetative plants. *Annals of Botany, 36,* 431–441.

Thornley J.H.M., (1998). Modelling shoot: root relations: the only way forward. *Annals of Botany, 81,* 165 – 171.

Thornley, J. H. M. (1995). Shoot: Root allocation with respect to C, N, and P: an investigation and comparison of resistance and teleonomic models. *Annals of Botany, 75,* 391 - 405.

Tiwari, A., Dwivedi, A. K., & Dikshit, P. R. (2002). Long-term influence of organic and inorganic fertilizers on soil fertility and productivity of soybean-wheat system in a Vertisol. *Journal of the Indian Society of Soil Science, 50,* 472 – 475.

Tiwari, R. C. (2002). *Recycling of industrial organic wastes and urban digested sludge through integrated plant nutrient supply system.* Unpublished data of research project report submitted Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

Truog, E. (1930). The determination of readily available phosphorus in soils. *Journal Amer. Soc. Argon., 22,* 874 – 882.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, *37*(1), 29-38.

Wilson, J. B. (1988). A review of evidence on the control on shoot: root ratio, in relation to models. *Annals of Botany*, *61,* 433 - 449.

Wood, G. A., & Lass, R. A., (1985). *Cacao* (4th ed.). London, UK: Longman.

World Trade Organisation (WTO) (2008). *Trade policy review for Ghana.* Report No. WT/TPR/S/194. pp. 44-68. Available online at: www.wto.org/english/tratop_e/tpr_e/s194-04_e.doc. Retrived on 5th May, 2009.

Yaduvanshi, N. P. S. (2003). Substitution of inorganic fertilizers by organic manures and the effect on soil fertility in rice–wheat rotation on reclaimed sodic soil in India. *Indian Journal of Agricultural Sciences 140*, 161–168.

Zhang, L., Feng, G., Declerck, S. (2018). Signal beyond nutrient, fructose, exuded by an arbuscular mycorrhizal fungus triggers phytate mineralization by a phosphate solubilizing bacterium. *ISME Journal, 12,* 2339–2351. doi:10.1038/s41396-018-0171-4, PMID.